FINAL REPORT

Demonstration and Validation of an Improved Airborne Electromagnetic System for UXO Detection and Mapping

ESTCP Project MM-0743

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14. ABSTRACT
This report documents the cost and performance of Battelle's new airborne time-domain electromagnetic system for mapping and detection of unexploded ordnance (UXO). This system has been developed to address shortcomings of magnetometer-based systems where the presence of basalt flows impede the performance of magnetometer systems. Two sites near Albuquerque, New Mexico were selected for demonstration: a 617-acre portion of the Former Kirtland Precision Bombing Range (FKPBR) and the Kirtland PBR-S12 Target (S12). The FKPBR area was chosen to enable comparison with previous ESTCP demonstrations of wide area assessment (WAA) technologies. The PBR-S12 site was chosen as being representative of sites where ground-based and airborne magnetometer data are ineffective for UXO mapping and detection due to interference from a basalt flow that is exposed across the entire site. Ground-based data were collected with an EM61 and 327 anomalies were evaluated by excavation with the conclusion that the TEM-8 demonstration exceeded all of the performance objectives.

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Acronym List

AFB	Air Force Base
AGL	Above ground level
ALASA	As Low as Safely Achievable
AS	Analytic signal
ASCII	American Standard Code for Information Interchange
ADU	Attitude determination unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data analysis system
DoD	Department of Defense
DQO	Data Quality Objective
DSP	Digital Signal Processor
EM	Electromagnetic
EMI	Electromagnetic Investigation
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FKPBR	Former Kirtland Precision Bombing Range
FOM	Figure of Merit
FP	False Positive
FUDS	Formerly Used Defense Sites
GIS	Geographic Information System
GPS, DGPS	(Differential) Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
HEAT	High Explosive Anti-tank Warhead
Hz	Hertz
IDA	Institute for Defense Analyses
INS	U.S. Immigration and Naturalization Service
IR	Improvement Ratio
m	meters
MCAGCC	Marine Corps Air Ground Combat Center
MEC	Munitions and Explosives of Concern
MTADS	Multiple Towed Array Detection Systems
NAD	North American Datum
NRL	Naval Research Laboratory
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
nT/m	nanoteslas per meter
PBR	Precision Bombing Range
Pd	Probability of Detection
ppm	parts per million
RAAF	Royal Australian Air Force
RMS	Root Mean Square
ROC	Receiver Operating Characteristic

SERDP	Strategic Environmental Research & Development Program
S/N	Signal-to-noise ratio (S/N)
SORT	Simulated Oil Refinery Target
SNR	Signal to Noise Ratio
STC	Supplemental Type Certificate
TEM	Time-Domain Electromagnetic
TIF, GeoTIF	(Geographically referenced) Tagged Information File
TF	Total (magnetic) field
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
VG	Vertical (magnetic) gradient
VSEMS	Vehicular Simultaneous Electromagnetic Induction and Magnetometer System
WAA	Wide Area Assessment

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Executive Summary

In September 2008, Battelle completed a new airborne time-domain electromagnetic system for mapping and detection of unexploded ordnance (UXO). This system was developed with corporate funds on the basis of successful evaluation of a prototype system under the Environmental Security Technology Certification Program (ESTCP) Project 200101. This system has been developed to address shortcomings of magnetometer-based systems where the presence of basalt flows or other iron-bearing soils and rocks impede the performance of magnetometer systems. Although this is not a universal problem, it occurs with varying degrees of severity, at many sites in the western continental U.S. as well as portions of Hawaii and Alaska.

The Battelle Time-Domain Electromagnetic (TEM)-8 system is contained within a 12 by 3 meters (m) rectangular boom structure with a two-lobed transmitter loop composed of two 3 by 4 m rectangles. There are four receivers on each side of the aircraft, located within 4 m tube segments that are oriented parallel to the long axis of the boom structure. As with most transient Electromagnetic (EM) systems, a current is established in the transmitter loop, then rapidly switched off, inducing a secondary magnetic field in the earth, the decay of which is measured in the receiver coils. Because the central third of the boom structure directly under the helicopter is inactive, it is necessary to interleave flight lines in order to achieve full coverage of the underlying subsurface.

Two sites near Albuquerque, New Mexico were selected for a February 2009 demonstration: a 617-acre portion of the Former Kirtland Precision Bombing Range (FKPBR) in New Mexico, and the Kirtland Precision Bombing Range (PBR)-S12 Target (S12). The FKPBR area was chosen to enable comparison with previous ESTCP demonstrations of wide area assessment (WAA) technologies, and because moderate basaltic interference has been recognized in some of the previous WAA demonstrations. A 100 acre area within the FKPBR area was specified for emplacement of seed items. The seed items were emplaced under the direction of the ESTCP Program Office without involvement from AMEC or Battelle. Validation of data from this area was made by the Institute for Defense Analyses (IDA) by comparing dig lists to a master list of seeded items. A total of 110 seed items were emplaced, including 81 millimeter (mm) and 4.2-in mortars, 105 mm projectiles and HEAT rounds, and 155 m projectiles. IDA determined that TEM-8 detected 109 of the 110 seed items, missing one 4.2-in mortar by only 1 centimeter (cm) outside of the 1.5 m detection halo. The mean miss distance was 0.34 m with a standard deviation of 0.23 m.

The PBR-S12 site was chosen as being representative of sites where ground-based and airborne magnetometer data are ineffective for UXO mapping and detection due to interference from a basalt flow that is exposed across the entire site. Airborne magnetometer data that were acquired in 2002 with the Oak Ridge Airborne Geophysical System (ORAGS)-Arrowhead system at PBR-S12 indicated no distinguishable response to ordnance at the target, even though a concentration of M38 scrap can be observed at the surface near the center of the target. The ordnance at the site consists almost exclusively of M38 fragments, with occasional M38s that are

largely intact. From the airborne data, two 100 by 100 m grids were selected for validation. Ground-based data were collected in these grids with an EM61, and 327 anomalies were evaluated by excavation. The validation indicated that all but two of the excavated items over 5 pounds (lbs) were detected by TEM-8, and 78 percent of the excavated items weighing between 1 and 5 lbs were detected. TEM-8 detected 31 percent of the M38 fragment which weighed less than 1 lb.

The TEM-8 demonstration exceeded all of the performance objectives that had been established in advance of the test. The results indicate that TEM-8 fills an important niche in WAA assessments by enabling the use of lower-cost airborne detection systems in areas where moderate to severe basaltic interference causes magnetometer systems encounter too many false positives or to miss ordnance altogether. It may also prove beneficial as a primary or supplemental system in areas where magnetometer system performance is acceptable.

INTRODUCTION

1.1 Background

It is estimated that Unexploded Ordnance (UXO) may contaminate 15 million acres or more within the United States alone. A need for improved technologies for mapping and detection of UXO has led to development of a sequence of airborne reconnaissance systems, using electromagnetic (Beard et al., 2004; Doll et al., 2005; Holladay et al., 2006) and magnetic (Gamey et al., 2004) sensors.

In 2002, Battelle staff (then at Oak Ridge National Laboratory [ORNL]) evaluated a prototype time domain electromagnetic system for mapping and detection of unexploded ordnance (Oak Ridge National Laboratory, 2005). This study demonstrated excellent sensitivity to ordnance when the system was flown at sufficiently low altitudes, but the system lacked the necessary efficiency for production-scale operations, due to the fact that it had only two receiver channels.

Based on the success of the 2002 tests, Battelle committed corporate funds to design and construct a new system, similar to the Oak Ridge Airborne Geophysical System (ORAGS)-Time-Domain Electromagnetic (TEM) system in many regards, but having eight receiver coils instead of two. The Battelle TEM-8 system was first deployed in a shakedown test at Battelle's West Jefferson Ohio UXO Airborne System Test Site in November 2007. It was subsequently deployed at Marine Corps Air Ground Combat Center (MCGACC) Twentynine Palms, California and at Royal Australian Air Force (RAAF) Amberley, Australia during calendar year 2008. At Twentynine Palms, it was used in combination with the Vertical (magnetic) gradient (VG)-22 magnetometer system to demonstrate the benefits of these two technologies. At RAAF Amberley, the TEM-8 system was used to gather data at sites where large magnetic anomalies were observed in VG-16 magnetic data, to help in distinguishing between geologic and man-made targets.

1.2 Objectives of the Demonstration

There are two distinct objectives for this demonstration. First and foremost, it provides a means of assessing the effectiveness of the new TEM-8 airborne time-domain electromagnetic system in comparison with airborne magnetometer systems for mapping and detection of ordnance. This is assessed in two areas, one with mild geologic interference, and one with severe geologic interference, associated with basalts.

A second objective of the demonstration is to assess the effectiveness of the TEM-8 system for Wide Area Assessment (WAA) applications. The Demonstration Site for this project has been used for previous WAA demonstrations, and therefore allows a basis for achieving this second objective.

1.3 Regulatory Drivers

No specific regulatory drivers influenced this technology demonstration. UXO-related activity is

generally conducted under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority. Regardless of a lack of specific regulatory drivers, many Department of Defense (DoD) sites and installations are aggressively pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. burial sites) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites can lead to airborne surveying and other remediation activities despite the absence of relevant regulatory drivers and mandates.

TECHNOLOGY

1.4 Technology Description

The recently-developed Battelle TEM-8 time-domain electromagnetic system was deployed at the Former Kirtland Precision Bombing Range (FKPBR), and at the Kirtland Precision Bombing Range (PBR)-S12 site, both in New Mexico. This system has been developed to address shortcomings of magnetometer-based systems that occur at certain DoD sites. Photograph 1 shows the system during aerial maneuvers. First and foremost, it has been anticipated that the TEM-8 system will prove superior to magnetometer systems where the presence of basalt flows impedes the performance of the magnetometer systems. Although this is not a universal problem, it occurs with varying degrees of severity, at many sites in the western continental United States as well as portions of Hawaii and Alaska. Secondarily, an electromagnetic system would prove beneficial at sites where non-ferrous ordnance might occur, or where more attributes derivable from TEM-8 data could provide a cost-effective reduction in the number of targets requiring further ground-based evaluation.

Photograph 1. TEM-8 airborne electromagnetic system.

A pre-demonstration test of the TEM-8 system was conducted at the Battelle West Jefferson Test Site in July 2008. The West Jefferson (Ohio) site, six acres in size, is located in an area where a glacial till layer, typically 50–200 feet (ft) thick, overlies Silurian age carbonate bedrock. The glacial till layer contains rocks with a wide variety of compositions and sizes, some of which can generate significant magnetic anomalies at the site. Ground-based Electromagnetic (EM)61 and magnetic gradient data have been acquired at the site, as well as airborne vertical magnetic gradient measurements. Ordnance types and quantities emplaced at the site are summarized in Table 2-1. A map view of the items in the test grid is depicted in Figure 1, with labels indicating depth (in meters[m]) and orientation for each item.

Table 2-1: Quantities of Ordnance Items Emplaced at West Jefferson Airborne UXO Test Site.

Description	**Number of Items**	**Mass** (kg)
155	13	24.1-26.5
105 M60	11	9.5-12.7
MK76	3	11.2
60 mm mortar	19	1.0-1.1
81 mm mortar	20	3.2
M12 AT mines	2	3.7
M20 AT mines	2	4.1
5-in rocket	1	
3-in Stokes mortar	3	3.0-3.7
2.75-in	1	
M38	2	
MK-118 submunitions	3	0.6
75mm	1	
Propane tank	2	
Aluminum plate	4	
TOTAL Individual Items	**87**	

mm = millimeter, AT = antitank, kg = kilogram

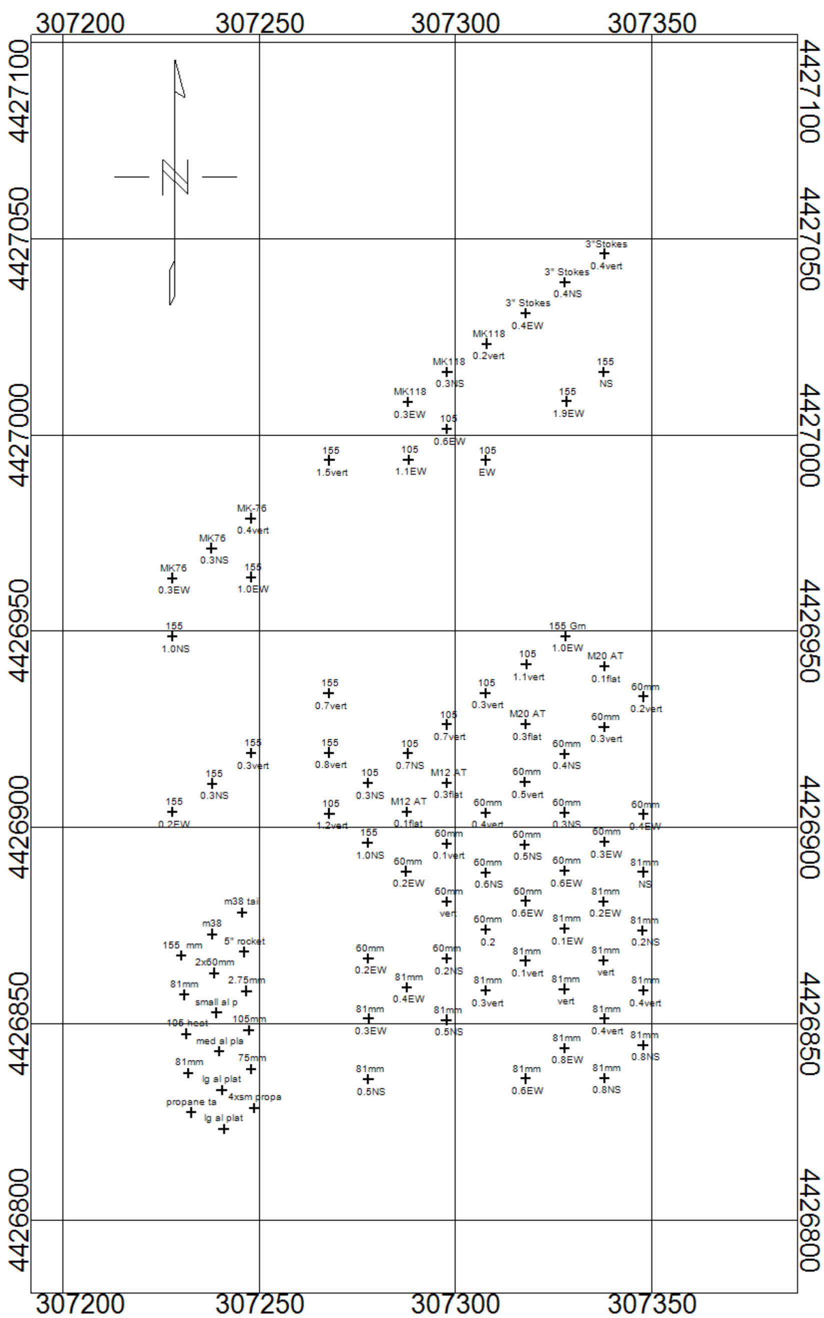

Figure 1. Map of items in the West Jefferson Test grid, showing depth and orientation for each item. Grid lines are on 50 m.

1.5 Technology Development

Development of the TEM-8 system was conducted with Battelle internal funds, and was not included in this project.

1.6 Advantages and Limitations of the Technology

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at a site at considerably lower cost per acre than ground-based systems. Furthermore, the data may be acquired in a shorter period of time. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys. Performance of airborne systems is clearly lower than that of ground-based systems (e.g. towed array surveys using the Vehicular Simultaneous Electromagnetic Induction and Magnetometer System, or 'VSEMS'), which can operate with sensors at less than 0.5 m AGL.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation can limit the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items. The performance of ground-based electromagnetic systems has been proven superior to magnetometer systems where basaltic rocks are problematic. The airborne TEM-8 system demonstrates a similar advantage over airborne magnetometer systems under the same geologic conditions. TEM-8 does not perform as well as magnetometer systems for altitudes 2 m and higher where magnetic geology is not problematic.

The primary advantage of the airborne technology is the capability to survey large areas more quickly and cheaply than conventional ground-based surveys. Ground-based electromagnetic systems are preferred over ground-based magnetometer systems, even when geology is not magnetic, if target ordnance are at shallow depths. Ground-based magnetometer systems are usually preferred over ground-based electromagnetic systems for deep ordnance items. Similarly, airborne electromagnetic systems are less sensitive to deep ordnance than airborne magnetometer systems. The primary advantage of airborne electromagnetic systems over airborne magnetometer systems will be for sites with significant magnetic geologic interference, or where items targeted are largely non-magnetic. Airborne systems also have an advantage in areas where ground access is limited or difficult due to surface conditions (swamp or marsh) or inherent danger (exposure to UXO or other contaminants). Areas with a sensitive ecological environment may also benefit from the less intrusive airborne technologies.

PERFORMANCE OBJECTIVES

Effectiveness of the demonstration is determined from comparisons of the processed/analyzed results from the demonstration survey and the established ground-truth. Some qualitative parameters may be judged against results of previous airborne and ground-based surveys at FKPBR and elsewhere. However, no baseline performance metrics are available for airborne EM systems, other than the informal results from the ORAGS-TEM system at the Badlands Bombing Range (ORNL, 2004). Evaluation of seeded items provides a basis for assessing detection of ordnance items. These comparisons include both the quantitative and qualitative items described in this section. Demonstration success is defined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established in Table 3-1. Methods utilized by Battelle on both current and past airborne acquisitions to ensure airborne survey success include daily quality assurance (QA)/quality control (QC) checks on all system parameters (e.g. GPS, sensor operation, data recording, etc.) in the acquired data sets, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase. Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Therefore, it is difficult to obtain as much precision and repeatability as one might want for comparing system performance. Data processing involves several steps, including Global Positioning System (GPS) post-processing, spike removal, time lag correction, filtering to remove helicopter-related noise, and gridding for QC and map presentation.

The performance objectives for the TEM-8 are summarized in Table 3-1. Depth estimates are not made from the TEM-8 data, but the depths of emplaced and excavated targets will be recorded as a parameter for characterizing the depth sensitivity of the system. Items that are detected, as well as those that are missed have been reviewed to assess any role that their depth may have played.

Table 3-1: Performance objectives of TEM-8 system.

Performance Objective	Metric	Data Required	Success Criteria	Results
Quantitative Performance Objectives				
Detection[1] of all munitions of interest (moderate geologic interference)	Percent detected of seeded items (FKPBR)	Location of seeded Items Prioritized dig list	Probability of detection (Pd) per item as summarized in Table 3-2.	Detected 99.1 percent of seeded items at FKPBR, exceeding success criteria for all ordnance types per Table 3-2.
Detection[1] of all munitions of interest (extreme geologic interference)	Percent detected of items identified in EM61 survey (PBR-S12)	Dig list from EM61 survey Prioritized dig list from TEM-8 Locations from validation survey	Detect 90 percent of M38 at PBR-S12	Detected 95 percent of largely intact M38s at PBR-S12
Reduction of false alarms relative to magnetometer measurements (PBR-S12)	Percent of False positives[2] at PBR-S12	Dig list from EM61 survey Prioritized dig list from TEM-8 Locations from validation survey	Equal numbers of false positives and successful detections at Improved signal-to-noise ratio (S/N) of 2:1 for M38s or other ordnance types at PBR-S12	81.3 percent of digs from TEM-8 list were successful in finding M38s or M38 frag (157 of 193 digs). False positives constituted 18.7 percent
S/N of EMI over magnetics in adverse geologic settings (PBR-S12)	Signal-to-noise ratio[3] at PBR-S12.	Amplitude of TEM-8 detections Amplitudes of previous magnetic detections Gridded TEM and magnetic data sets	TEM SNR > mag S/N	At PBR-S12, the TEM-8 SNR is estimated to be more than 1200 times as large as the magnetometer Signal to Noise Ratio (SNR). At FKPBR, where geology is less severe, a representative quiet area had similar SNRs, while in a noisier background; the TEM-8 SNR was about four times that of the magnetometer system.
Location accuracy	Average error and standard deviation for seed (FKPBR) and excavated (PBR-S12) items	Location of seed items surveyed to accuracy of 1 cm (FKPBR) Locations of excavated items to accuracy of 2 cm (PBR-S12) Estimated locations from analysis of TEM-8 data	90% of estimated locations for detected ordnance within 1.50 m of actual; ΔN and ΔE <0.5 m σN and σE <0.5 m	99 percent within 1.5 m at FKPBR, with mean miss distance of 0.34, and standard deviation (s.d.). of .23. At PBR-S12, all but three of 157 detected items were within 1.5 m, and the mean miss distance was 0.58 m with 0.31 m s.d.
Production rate	Number of acres of data collection per day	Log of field work	Survey: 125 acres per day	22.35 acres/hr. or 106.2 acres/day. Afternoon winds caused short days

Performance Objective 9 *(Continued)*	**Metric** *(Continued)*	**Data Required** *(Continued)*	**Success Criteria** *(Continued)*	**Results** *(Continued)*
Qualitative Performance Objectives				
Ease of use		Pilot approval		Flight performance is acceptable.
Terrain/vegetation restrictions		Acceptable for targets of interest		Sensitivity falls off markedly above about 3.5-4.0 m altitude, where higher altitude caused by vegetation.
Aerodynamic stability		Safety, certification, no restrictions		Airspeed limited to 70 knots
Detection capabilities		Superior delineation of ordnance compared to magnetometer systems in the presence of magnetic background		TEM-8 was unaffected by magnetic background. Performance relative to magnetometer systems depends on degree of magnetic interference

(1) We define the term "ordnance detection" to mean the percentage of ordnance items that produced electromagnetic anomalies discernable above the noise floor and within a defined search radius. The term does not imply that the anomalies were or were not correctly classified.
(2) By the term "false positive" we refer to an EM anomaly for which no metallic conductor can be associated.
(3) Signal-to-noise ratio (S/N) for both EM and magnetic systems is be calculated as the average peak amplitude of positive M38 detections divided by the Root Mean Squared (RMS) noise over the entire target area.

1.7 Objective 1: Detection of All Munitions of Interest (Moderate Geologic Interference)

The valuable contribution of the TEM-8 system should be in its detection capability. Discrimination among ordnance types is not an objective of this demonstration. Airborne geophysical systems do not distinguish between UXO and metallic scrap for the many anomalies mapped without interpretation. The maps depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of metallic debris associated with human activity), and potential UXO items (discrete sources). Those responses interpreted as potential UXO likely also include smaller pieces of metallic debris. It is not the purpose of this test to discriminate between UXO and non-UXO items. At FKPBR, therefore, the performance is judged with regard to target types that have proven detectable at the Ohio test grid under controlled conditions. Here the detection capability is assessed over a large area with approximately 100 blind-seeded items, and the probability of detection (Pd) is calculated for each ordnance type separately.

Metric

We compare the number of ordnance items of each type to the total number of seeded items. The anticipated detection rates are listed in Table 3-2. Data collection occurred at minimum safe flight altitude over the various test areas.

Table 3-2: Anticipated detection rates for FKPBR seeded grid

Ordnance type	Expected Detection
81 mm	40%
105 mm Projectile	65%
105 mm HEAT	60%
4.2-in mortar	60%
155 mm	80%

HEAT= High Explosive Anti-tank Warhead, mm = millimeter

Data Requirements

Data requirements include a prioritized dig list that was provided to the Environmental Security Technology Certification Program (ESTCP) Program Office by the AMEC team upon completion of the survey of the specified 100-acre seed area. ESTCP compared this with a database of seeded item types and locations and provided the resulting Pd values.

Success Criteria

The objective is considered to be met if we achieve the expected levels of detection that are specified in Table 3-2. This assumes that the system would find primary application in WAA surveys of areas where geologic interference is problematic and where it is not critical to achieve 100 percent detection of ordnance.

1.8 Objective 2: Detection of All Munitions of Interest (Extreme Geologic Interference)

The purpose of this objective is to assess the TEM-8 performance at a site which is not artificially seeded (PBR-S12), where in situ M38 ordnance (or at least M38 fragment) is visible at the surface. It is also a site where previous airborne magnetometer surveys have been completely ineffective.

Metric

The detection of M38s at PBR-S12 is assessed by a validation exercise in which EM61 survey results were used to select dig locations, and the results of the validation digs are compared against the anomaly list provided from the TEM-8 survey. The Pd is 90 percent for M38s at PBR-S12.

Data Requirements

Data required include a TEM-8 dig list, an EM61 dig list, and validation dig results for each selected anomaly. AMEC validated 327 targets within two 100 by 100 meter grids within which the EM61 data were acquired.

Success Criteria

This objective is considered to be met if 90 percent of the largely-intact M38 ordnance items recovered from the site are detected. For detection purposes, a “largely-intact-M38” is defined as any M38 related ordnance or frag larger than 50 x 24 cm, or any intact tail-fin.

1.9 Objective 3: Reduction of False Alarms (PBR-S12)

Because a full validation is not being conducted at FKPBR, we cannot assess false alarms from data acquired at that site. At PBR-S12, however, an approximation to false alarms can be made from the validation areas. Results from a 2002 ORAGS-Arrowhead magnetometer survey provide a comparable magnetic database. These data were picked and validated against the same ground truth.

Metric

The distribution of ordnance and ordnance debris at PBR-S12 was very sparse in some places, and we want to avoid choosing validation areas that are devoid of targets. Therefore, validation areas were selected from areas that show concentrations of discrete anomalies in the airborne data. Within these areas, EM61 data were acquired and anomalies from the EM61 data were subsequently validated by excavation. False alarms, defined as anomalies produced by non-metallic sources, are documented.

Data Requirements

Data required include the previous airborne magnetic data, TEM-8 grids for PBR-S12, the TEM-8 dig lists for the selected areas, EM61 data for the selected areas, and dig results for those areas.

Success Criteria
The objective is considered to be met when the number of false positives in the TEM data is less than the number in the magnetic data. This indicates substantially lower sensitivity to geologic features than magnetometer systems in this extreme geologic condition. Signal-to-noise is calculated as described in Section 6.2.

1.10 Objective 4: Improved Signal-To-Noise Ratio

A quantitative measure of the improvement in signal-to-noise ratio is a key metric in terms of defining the benefit of TEM over magnetic data in magnetically active geologic backgrounds. Measurements were made over PBR-S12 where both magnetic and electromagnetic data have been collected

Metric
Signal-to-noise ratio is calculated as described here and in Section 6.2. Electromagnetic signal strength was measured over M38 targets placed in the test grid. Magnetic signal strength is measured from previous survey results at typical survey altitudes. Noise is measured as the mode of the gridded data over the PBR-S12 area. The processed TEM-8 response is used for the electromagnetic system, and the calculated analytic signal is used for the magnetic system.

Data Requirements
Data from the previous magnetic survey of PBR-S12 as well as the new TEM data are required.

Success Criteria
The objective is considered successfully met when the signal-to-noise ratio of the TEM is greater than that of the magnetic data.

1.11 Objective 5: Location Accuracy

The positional accuracy is an important constraint for enabling satisfactory ground follow-up of anomalies and can be measured from both the FKPBR and PBR-S12 datasets.

Metric
Positional accuracy is determined by comparing the positions of anomalies in the PBR-S12 validation areas and in the FKPBR seeded area to the positions of those items provided by the PBR-S12 validation and by the ESTCP Program Office after the “dig lists” are provided to ESTCP by Battelle. Mean offset is determined in addition to the distribution of errors relative to the zero-mean position.

Data Requirements
Data required are the TEM-8 dig lists for PBR-S12 and FKPBR seeded area, the precise locations of seeded items, and the locations derived from validation of anomalies at PBR-S12.

Success Criteria
This objective is considered successful when 90 percent or more of the seeded items and validated targets are located within 1.50 m of their actual locations. Further, locations should exhibit:

average positioning error:
$\Delta X_{mean} = \Sigma(X_{obs} - X_{actual})/N$ and $\Delta Y_{mean} = \Sigma(Y_{obs} - Y_{actual})/N$ of < 0.5m

and

standard deviations:
$\sqrt{(\Sigma(\Delta X_i - \Delta X_{mean})^2/N)}$ and $\sqrt{(\Sigma(\Delta Y_i - \Delta Y_{mean})^2/N)}$ of < 0.5 m.

1.12 Other Critical Data That Are Documented

The performance of an airborne system is influenced by parameters that cannot be specified in advance, but which influence the effectiveness of the technology. These are documented to allow their consideration in future surveys.

System Noise and Survey Noise
The noise performance of the TEM-8 system is assessed by measuring the average noise at altitude where geologic interference would be nominal. This approach is preferred over noise measurements based on gridded data, as it is less susceptible to confusion associated with smoothing and gridding parameters. This system noise controls the ability of the system to detect target items in the absence of any unfavorable background at any particular site.

In addition, a practical noise parameter is determined, "survey noise", which is a composite of the system noise and geologic interference at the site, as determined from data acquired at survey altitudes. This noise ultimately constrains the ability of the system to detect ordnance at the particular site where the data were acquired. It is measured from gridded data at selected altitudes in an area that appears to be devoid of ordnance or other metallic debris after all filters have been made in the same manner as in the data set as a whole.

Altitude
Survey altitude varies with topography, surface conditions, wind, and other flight conditions along each survey line. Sensor altitudes are calculated based on the system geometry from the central laser altimeter with an accuracy of +/- 2 centimeter (cm), and adjusted for the system roll as measured between two dual-phase GPS antennae. In general, all flights are flown as low to the ground as is safely possible. Some flights are intentionally flown higher for demonstration purposes. Data presented in gridded format generally represent a single survey height.

SITE DESCRIPTION

The two areas that were selected for this demonstration are a 617-acre portion of the FKPBR (Table 4-1; Figure 2 and Figure 3) and a 444-acre area surrounding the center of PBR-S12 (Figure 4). A 100 acre area within the FKPBR area was specified for emplacement of seed items, to be emplaced under the direction of the ESTCP Program Office without involvement from AMEC or Battelle.

Table 4-1: Breakdown of proposed survey blocks for Battelle TEM-8 system at FKPBR.

Area	Altitude	Purpose
FKPBR-600	ALASA*	To allow comparison of TEM-8 survey noise and ordnance detection to airborne magnetic data, previously acquired by another contractor.
FKPBR-100	ALASA*	To assess TEM-8 sensitivity to seeded items, emplaced under the direction of the ESTCP Program Office
PBR-S12	ALASA*	To assess TEM-8 performance of detection of M38 practice bombs in an area where basaltic contamination is severe.

* ALASA – As Low As Safely Achievable

1.13 Site Selection

Two sites were selected for this project. The ESTCP Program Office has requested that survey data be acquired at the Former Kirtland Precision Bombing Range (FKPBR) in New Mexico, where previous WAA surveys were conducted. Corner coordinates for the areas flown at FKPBR and PBR-S12 and the blind seeded area at FKPBR are provided in Table 4-2 and are in Universal Transverse Mercator (UTM) Zone 13 North (N) coordinates.

Table 4-2: Corner Coordinates for the recommended survey and seed areas.

Corner Coordinates for the recommended survey area at FKPBR		Corner Coordinates for the recommended Seed area at FKPBR		Corner Coordinates for the Recommended Survey Area at PBR-S12	
Easting	**Northing**	**Easting**	**Northing**	**Easting**	**Northing**
330400.00	3894450.00	331707.00	3893100.00	304500.00	3858000.00
332200.00	3894450.00	331000.20	3893107.00	306000.00	3858000.00
332200.00	3893100.00	331000.20	3893686.30	306000.00	3856900.00
330400.00	3893100.00	331707.00	3893686.30	306000.00	3856900.00

All coordinates are in meters (UTM Zone 13)

Figure 2 and Figure 3 are associated with the FKPBR site. It is thought that a demonstration in this area can provide valuable comparisons with other WAA survey tools while reducing overall cost of the demonstration to ESTCP.

Figure 3 depicts total field magnetic anomaly map of the area at FKPBR that was surveyed by Sky Research in an earlier 2005-6 ESTCP WAA project. The inset shows the location of the 100-acrea area selected for blind-seeding. The area of interest shows generally moderate, and

locally severe, interference from basalts. The 100-acre area was also flown by Sky Research in 2009 with a newer airborne magnetometer system for ESTCP.

Figure 4 is a map of the FKPBR site, showing the two areas adjacent to Double Eagle Airport that were surveyed in previous ESTCP WAA projects. The proposed 600 acre survey area is shown in red. The blue box within the proposed survey area represents the 100 acre area for emplacement of seed items. The green circle is approximately where the N-3 target area is located. Locations of previous ground surveys (provided by M. May, IDA) are included as smaller rectangles. Perimeter polygons for the north and south areas provided by H. Nelson.

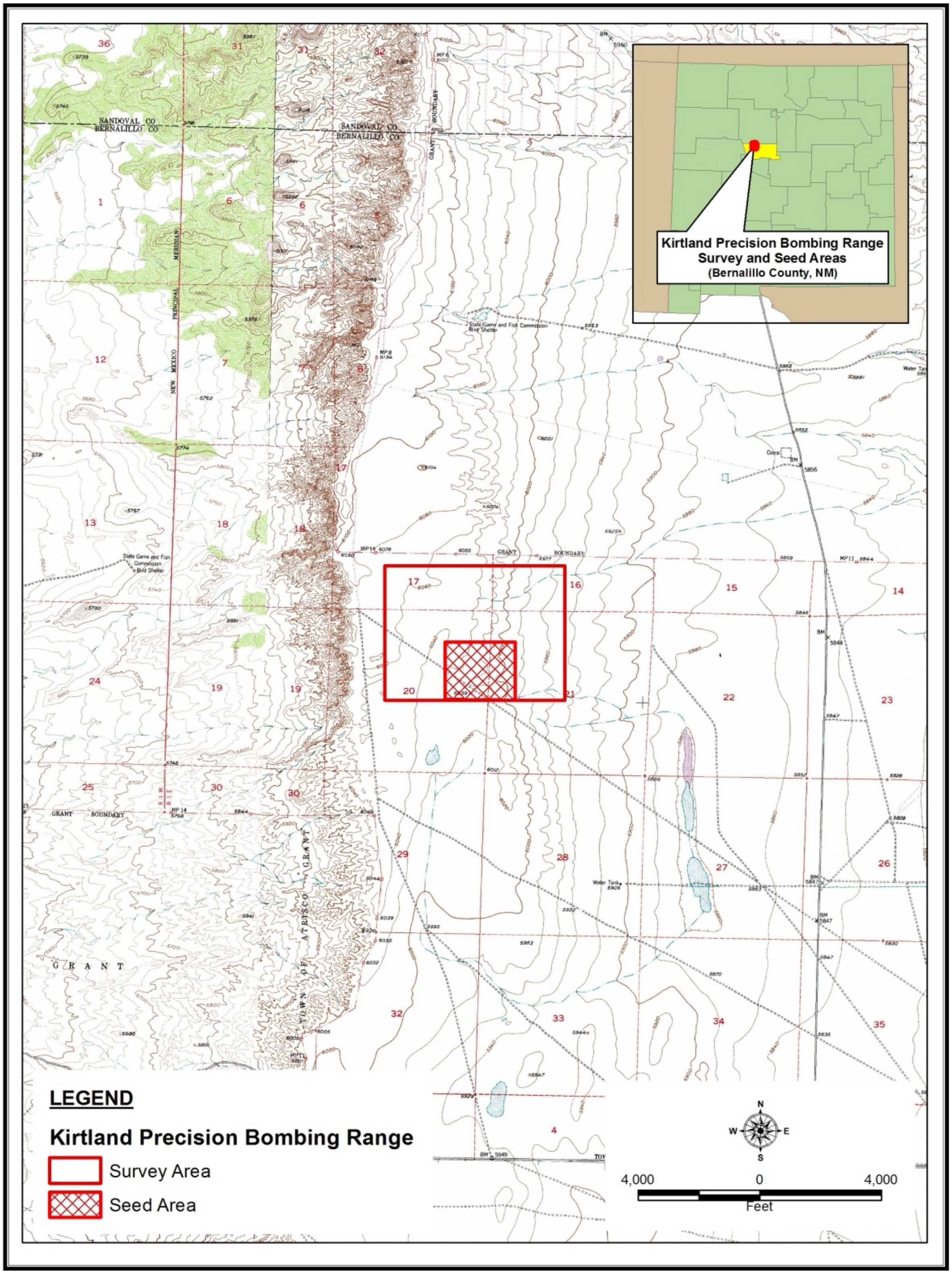

Figure 2. Map of the Former Kirtland Precision Bombing Range site.

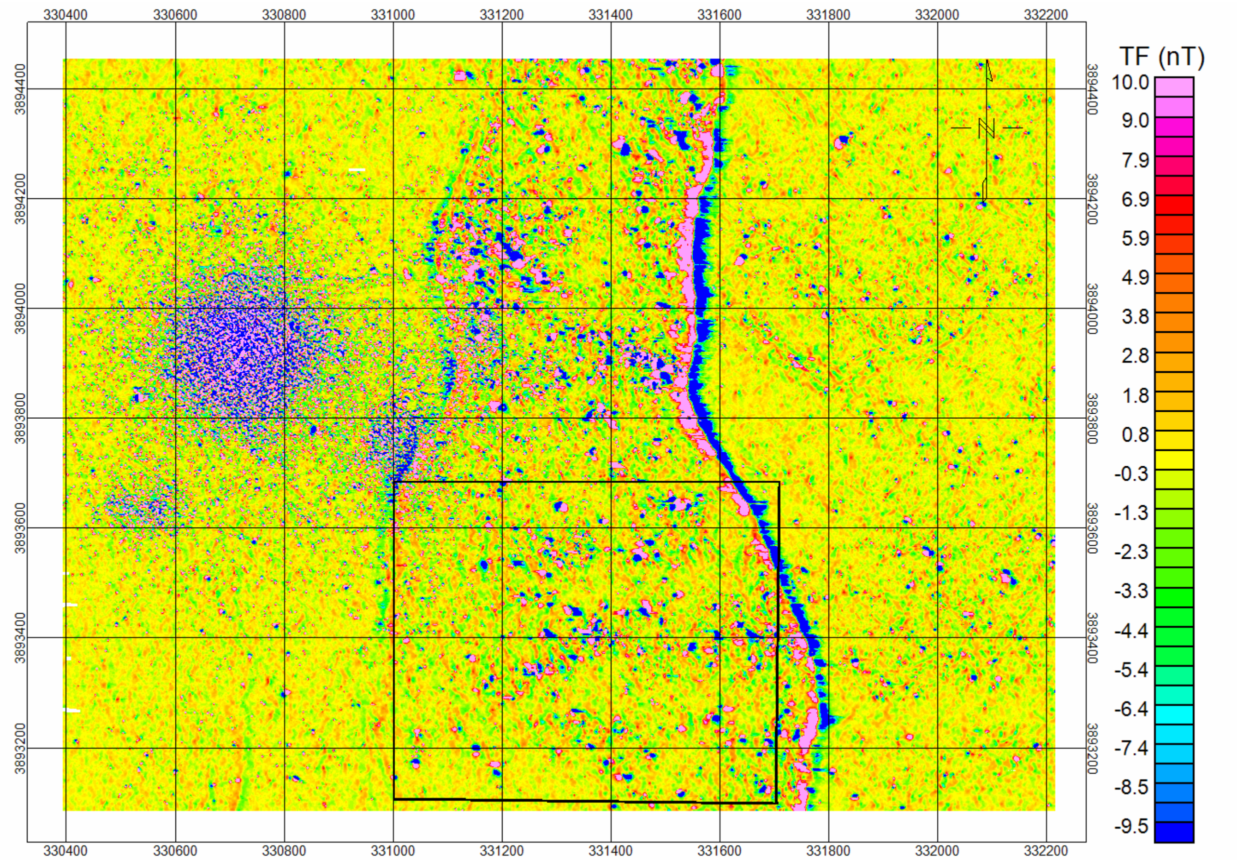

Figure 3. Total field magnetic anomaly surveyed by Sky Research

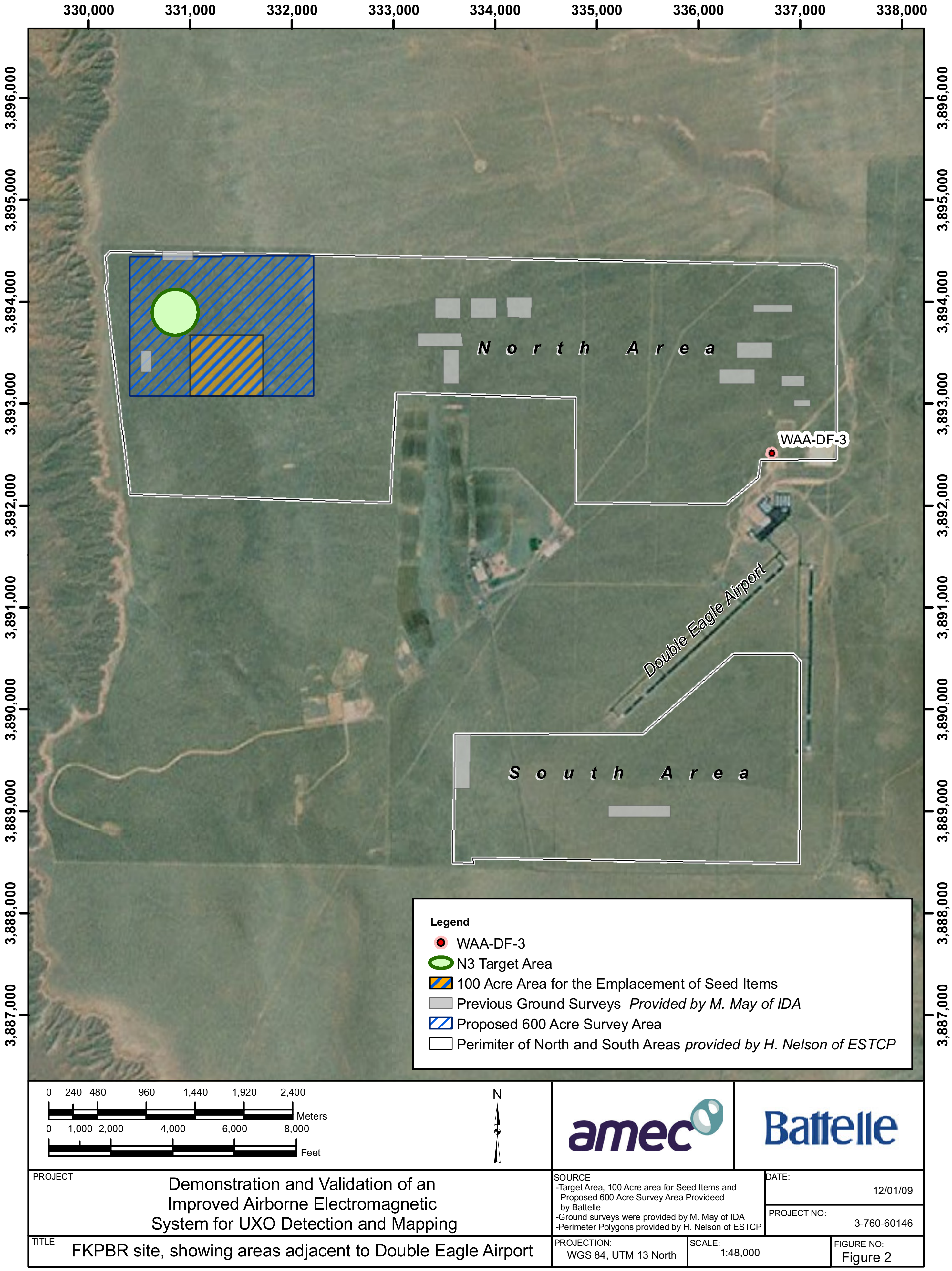

Figure 4. Map of the FKPBR site, showing areas adjacent to Double Eagle Airport

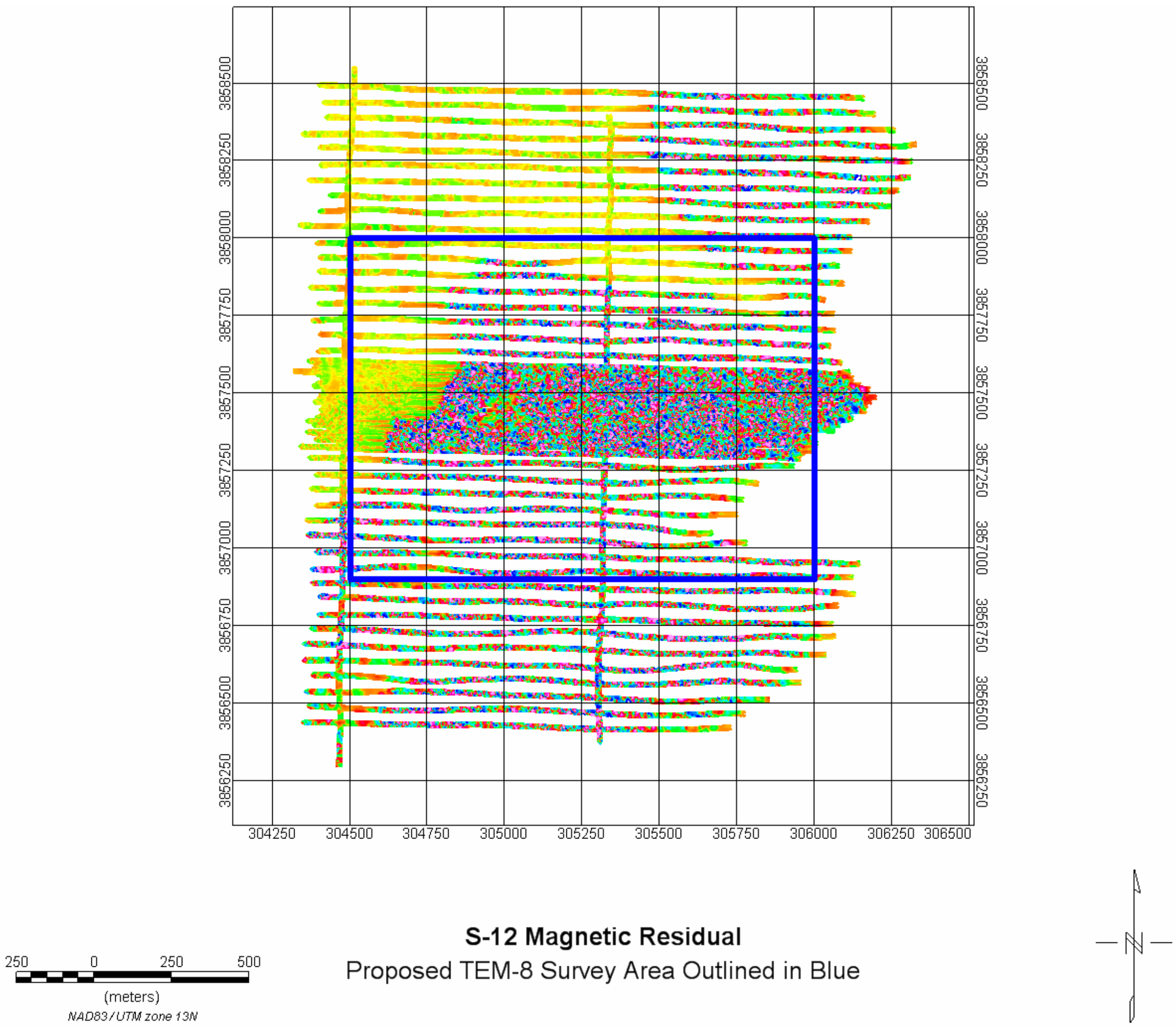

Figure 5. Recommended 400 acre TEM-8 survey area. Kirtland PBR-S12 Target (blue box) superimposed on the Arrowhead magnetic map of the site, acquired in 2002. The area was selected to allow comparison of magnetic and TEM-8 data, and to encompass both basaltic and non-basaltic areas at PBR-S12. The area selected is centered on the target.

Survey data were also acquired at the Kirtland PBR-S12 Target (S12) (see Figure 4 and 5). This site was chosen as being representative of sites where ground-based and airborne magnetometer data are ineffective for UXO mapping and detection due to interference from basalts. Airborne magnetometer data were acquired with the ORAGS-Arrowhead system at PBR-S12 and show no distinguishable response to ordnance at the target, even though a concentration of M38 scrap can be observed at the surface near the center of the target (Photograph 2).

Photograph 2. Photograph, looking north across the center of the PBR S-12 target. The pile of M38 scrap in the center of the photograph was not detected by the airborne magnetometer survey.

1.14 Site History

The FKPBR site is a 38,000-acre formerly used defense site (FUDS). It has been subject to previous geophysical surveys and partial excavation, primarily under the guidance of the ESTCP Program Office. It is currently undeveloped. It was used in World War II as a training area for Kirtland Air Force Base. The ESTCP WAA pilot study area consists of 5,000-6,500 acres adjacent to Double Eagle Airport, near Albuquerque NM. There are at least three bombing targets and a Simulated Oil Refinery Target (SORT) within this study area. Known or suspected ordnance types at the site are M38 practice bombs and 250-lb high explosive bombs. The portion of the FKPBR that was flown by TEM-8 includes the N-3 target area which is just northwest of the seeded area and two smaller targets adjacent to N-3 (see Figure 4)

The Kirtland PBR-S12 Target is located within land owned by the Pueblo of Laguna and is a FUDS located about 35 miles west of Albuquerque in New Mexico. The predominant ordnance

type at the site is World War II vintage M38s. The Pueblo of Laguna land totals more than half a million acres, and large portions of this typically western desert environment are flat and devoted to ranching. The remaining portions of land are gently rolling to nearly vertical in relief and were formed by extensive erosion of the soft fine-grained underlying sediments, creating canyons, washes, and gullies.

1.15 Site Geology

The sites are situated on the eastern edge of the New Mexico portion of the Colorado Plateau, east of the Albuquerque-Belen Basin. A series of strong north-south trending high-angle faults separate the geologic provinces, stepping downward from the plateau into the basin. The geology of the area is dominated by both consolidated and unconsolidated units and includes sandstone, mudstone, claystone, and shale. Igneous basalt formations cap the mesas in the area (e.g. Mesa Lucero, where the PBR-S12 target is located). In other locations, basalts have emanated from fissures or vents, provide sources for mafic alluvium on a more moderate scale (e.g. FKPBR). Typical altitude is 5,000-6,000 feet above sea level.

1.16 Munitions Contamination

With regard to historical ordnance, numerous sites across the entire area were utilized for aerial bombardment activity. From both visual inspection and previous Naval Research Laboratory (NRL) Multiple Towed Array Detection Systems (MTADS) surveys, the principal ordnance type present at these sites is the M38 practice bomb. Evidence of these ordnance items is present on the surface at all sites used for this demonstration, with several hundred M38s excavated during the MTADS demonstration (McDonald and Nelson, 1999).

TEST DESIGN

1.17 Conceptual Experimental Design

The demonstration has been designed to address the most common situation where an airborne electromagnetic capability would be beneficial; that is where background geology causes moderate to severe performance issues for airborne magnetometer systems. Airborne systems are viewed primarily as tools for wide-area assessment, and as such are not required to achieve a high Pd. However, where geologic interference is severe, most frequently due to basalt, the magnetic response from ordnance may be orders of magnitude smaller than the local geologic response. In this project, we assess the performance of the TEM-8 system at one site where basalt causes severe problems for magnetometer systems and where M38s are the predominant ordnance type, and at a second site where geologic interference is less severe and where a suite of more challenging seed items were emplaced.

1.18 Site Preparation

The FKPBR (see Figure 2) is a 38,000 acre area that was used in World War II as a training area for Kirtland Air Force Base. The ESTCP WAA pilot study area consists of 5,000-6,500 acres adjacent to Double Eagle II Airport, near Albuquerque NM. Within this study area are at least three bombing targets, and a Simulated Oil Refinery Target (SORT). Known or suspected ordnance types at the site are M38 practice bombs and 250-lb high explosive bombs. A power line passes along the northern boundary of the area flown by TEM-8 in this project. Typical terrain at the FKPBR site is shown in Photograph 3.

Photograph 3. Typical terrain at the FKPBR site, with power line in the background.

1.19 System Specifications

The Battelle TEM-8 system is contained within a 3 by 12 m rectangular boom structure with a two-lobed transmitter loop composed of two 3 by 4 m rectangles. There are four receivers on each side of the aircraft, located within 4 m tube segments that are oriented parallel to the long axis of the boom structure (Figure 6). As with most transient EM systems, a current is established in the transmitter loop, then rapidly switched off, inducing a secondary magnetic field in the earth, the decay of which is measured in the receiver coils. Because the central third of the boom structure directly under the helicopter is inactive, it is necessary to interleave flight lines in order to achieve full coverage of the underlying subsurface.

The TEM-8 transmitter produces an alternating "castle" type waveform, as indicated in Figure 6.

Alternating positive and negative "on-time" current pulses with linear on- and off-ramps are separated by "off-time" periods during which the transient measurements are made. During the waveform's on-time, the transmitted magnetic field interacts with nearby conductive objects, initially inducing eddy currents. As the on-time magnetic field stabilizes, these eddy currents decay exponentially, and are at or near zero toward the end of the on-time.

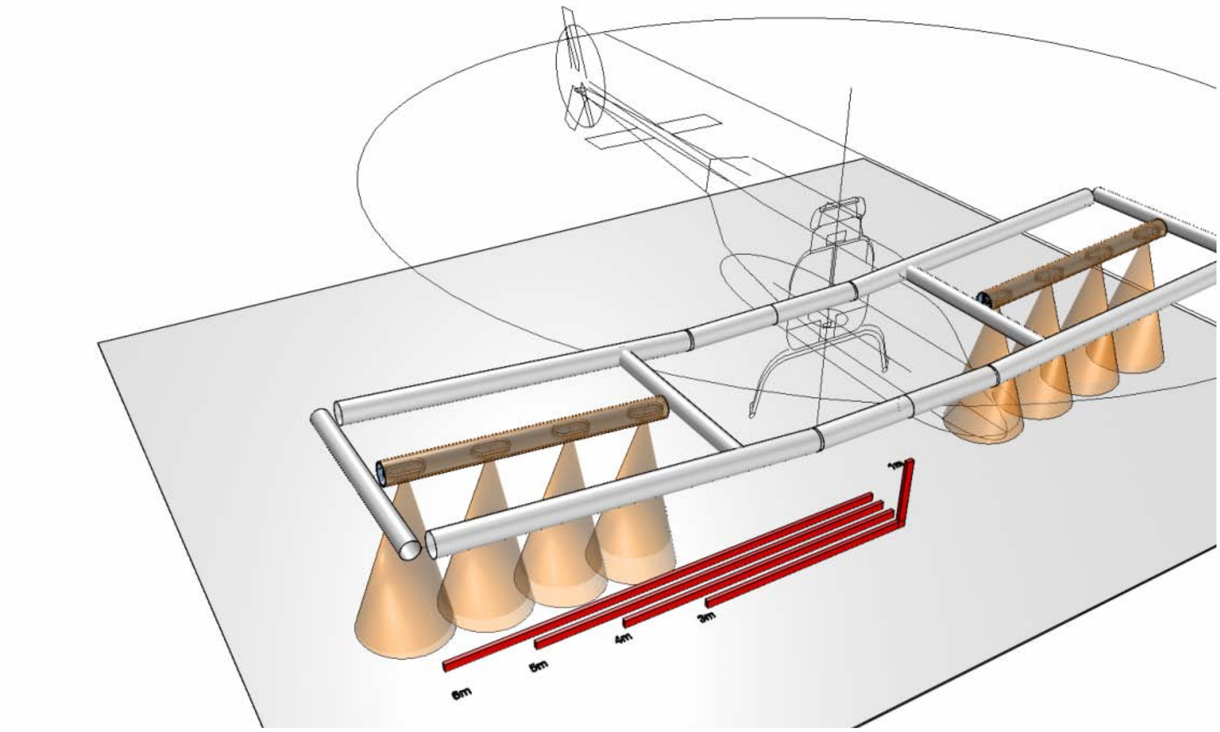

Figure 6. Diagrammatic sketch of the TEM- 8 system showing transmitter and receiver positions.

When the transmitted field is rapidly turned off, "early time" eddy currents are again generated at the surface of the conductive object, and these currents migrate into the object and attenuate in amplitude the off-time progresses. At "late time", the eddy current density becomes constant throughout the conductor and the secondary field due to the eddy currents decays with a single time constant.

For this demonstration, we used the 225 hertz (Hz) base frequency. The selection of base frequency is site-specific to some extent. We conducted test flights over the test grid at Kirtland at the beginning of the project with both frequencies 225 Hz and 270 Hz and chose the operating frequency of 225 Hz for the entire survey based on this test. Regardless of the base frequency used, the time gate structure remains the same. Samples are taken at 0.09 millisecond (ms) intervals. Gate 1 is one sample long, Gate 2 is two samples long, Gate 3 is four samples long, Gate 4 is eight samples long, etc to the end of the available off-time. A 270 Hz base frequency would compress the castle waveform into 1/3 the time shown for the 90 Hz base (Figure 7) and the first downward pulse would therefore occur shortly after the end of Gate 3.

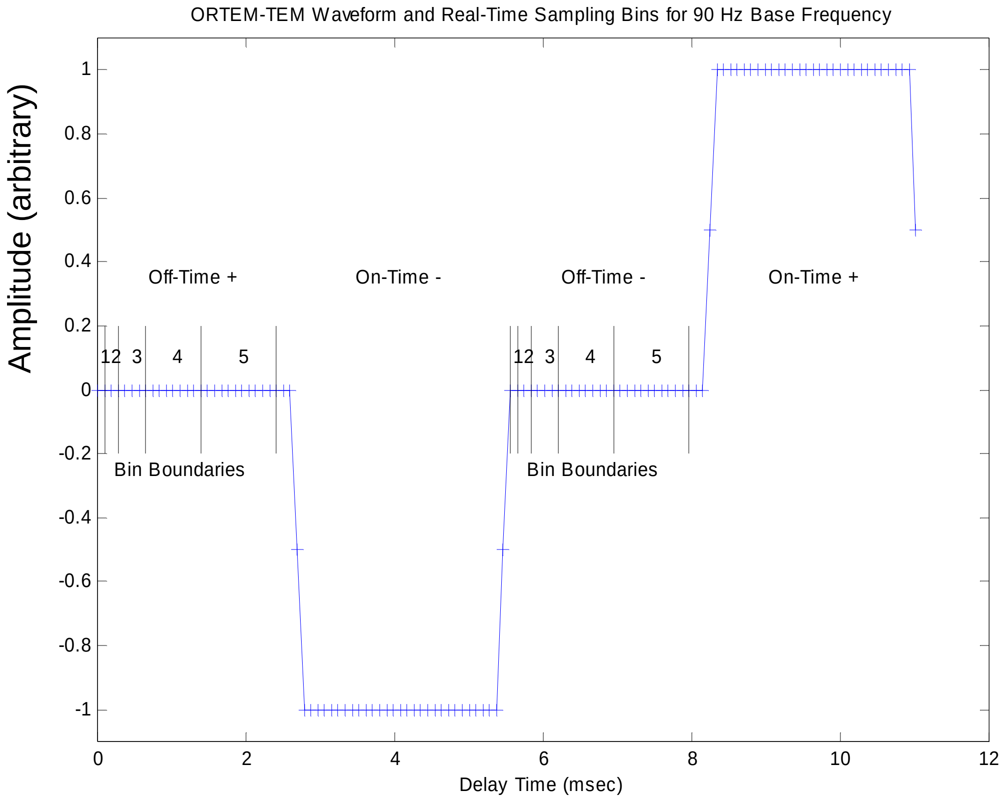

Figure 7. TEM-8 waveform and receiver sampling for 90 Hz base frequency. Cross symbols (+) indicate 10.8 kilohertz (kHz) sample locations, and real-time output data bins are indicated by the vertical lines and bin labels during the off times.

1.20 Calibration Activities

A test grid (two lines) was established by the demonstration team at FKPBR using test items similar to those emplaced in the blind-seeded area by the ESTCP Program Office. In addition, a few M38 practice bombs, largely intact were emplaced along with some M38 frag as provided by the demonstration team for calibration of the data from PBR-S12. The attributes of the test ordnance and test site were established by conducting an EM61 survey of the grid after emplacement. We used the same location for the grid that was used in a 2007 vertical magnetic gradient demonstration (Battelle, 2008a), where the background area proved to be geologically inert and largely metal free. Data were acquired at 225 Hz, 270 Hz, and 90 Hz base frequency. Results for the airborne system were gridded and used to select a base frequency for the remainder of the project. In addition, the test grid was surveyed each day to document system performance throughout the data acquisition process.

1.21 Data Collection

Scale-

As discussed in Section 4.1, data were acquired over a total of 1,062 acres at the two sites. This is sufficient area to demonstrate the technology for WAA purposes and to allow distribution of seed items within an area of sufficient size to be representative of WAA applications.

Sample Density-

The TEM-8 system acquires data at a line separation of 0.75 m and a down-line sample interval of a few cm, depending on base frequency and flight speed. Once the data are fully processed, a sample spacing of about 10 cm is typical. The scale of the anomalies (1.5-2.5 m or larger) at acceptable altitudes results in several measurements per anomalous response.

Quality Checks-

Methods utilized by Battelle on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters (e.g. GPS, sensor operation, data recording, etc.) in the acquired data sets, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase. Data are gridded daily to assure ongoing performance. Lines were re-flown when the daily QC checks showed gaps between lines, unacceptable altitude perturbations, or localized noise.

Data summary-

Data are stored on the recording console, and transferred at least daily to the desktop processing computer. Backups of data at selected levels of processing are stored on external hard drives and/or DVDs. The data are then stored on a large hard drive in the Oak Ridge Battelle offices. Upon completion of processing, all data including raw and processed products are archived and retained for future reference.

1.22 Validation

Validation of survey results was conducted on both the FKPBR and PBR-S12 survey sites. Without complete excavation of an area, the actual Pd and False Positive (FP) ratio cannot be calculated. For the blind test site (FKPBR), the Pd can be calculated but not the FP ratio, because the non-seed items were not excavated. At the live, double-blind site (PBR-S12) the number of excavations to fully characterize these parameters is prohibitive. However, the validation process still produces valuable information on system performance and the calculations demonstrate the potential Pd and FP ratio that might be obtained if a complete excavation were conducted.

At FKPBR, blind seed items placed by ESTCP are compared to dig lists derived from the TEM-8 data set. Dig lists from the airborne data were derived as described later in Section 6. A search radius of 1.5 m is used to determine whether a nearby anomaly constitutes a positive hit from the dig list. This provides the basis for calculating the Pd and location accuracy of the system in

accordance with Objectives 1 and 5. At the PBR-S12 site, ground-based geophysical surveys are used in conjunction with limited excavation to provide a basis for estimating a "potential" Pd, FP ratio, and location accuracy in accordance with Objectives 2, 3, 4 and 5 respectively. All positions reference survey monument WAA-DE-3. Survey procedures were documented and verified prior to final data analysis.

In addition to these blind validation tests, a calibration line of known items was established at FKPBR using items from the same inventory as the seeded items. A pre-seed EM61 survey was conducted over the area to avoid placing calibration items on existing anomalies. Targets were then seeded on the surface and their locations measured. A post-seed survey was conducted for comparison to the airborne data. This line was flown each day as part of the QC process, and the collected results were analyzed to demonstrate repeatability of detection and location accuracy.

At the FKPBR site, the attributes of each blind-seeded item was documented by ESTCP in a manner consistent with the USAESCH standard upon emplacement. After the team provided prioritized dig lists to ESTCP, the attributes for each test item at the site were released. These were used to produce conditional Receiver Operating Characteristic (ROC) curves and positional accuracy plots. For the purposes of calculating ROC curves, it is assumed that the seeded area is otherwise clear of ordnance. The overall ROC curves are further broken down by ordnance type and, if appropriate, ordnance to receiver offset (altitude + depth) to allow assessment of performance that could be expected at other sites, given expected target types and an anticipated altitude range.

Five validation grids were selected within the bounds of the PBR-S12 demonstration area. The grids were located in areas that contain a reasonable number of discrete anomalies that can be surveyed and excavated with the allotted budget. These areas were chosen in consultation with ESTCP. The grids avoided a known area where there is a high concentration of manmade debris (tin cans, household waste) at the surface. Two of these grids (Grid 1 and Grid 4) were selected by AMEC for follow-on investigation.

EM61 ground surveys were conducted over these two grids and a dig list was generated based on those data. The results of the calibration lane post-seed survey were used to establish a rough correlation between EM61 and TEM-8 amplitude response. The EM61 anomaly list was edited to remove all hits below a threshold equivalent to the TEM-8 picking threshold. The remaining anomalies were excavated and potential Pd FP ratio and location accuracy statistics were compiled. A search radius of 1.50 m was used.

DATA ANALYSIS AND PRODUCTS

1.23 Preprocessing

Data responses are acquired at 10.8 kHz sample rate and binned into time gates. The number of available time gates depends on the base frequency used, with more gates at lower frequencies. A digital signal processor (DSP) in the console conducts initial data reduction tasks prior to data storage. The DSP calculates the response values in each of the selected time gates, inverts the

responses from the negative transmission pulses, and stacks between two and six sets of values before storage. For UXO detection applications the higher base frequencies are preferred. At 270 Hz base frequency, three time gates are available. Maps were produced from a single time gate based on initial assessment of noise properties for each individual time gate. Typically, Bin 2 is selected, because it maximizes the spatial resolution of the data and the helicopter noise rejection capabilities. Additional processing steps are conducted subsequently to filter helicopter noise, remove instrument drift, minimize effects of ground conductivity, integrate base-station corrected positioning data and grid the data.

The quantity measured at the receiver is the temporal rate of change in the magnetic field as the field decays from its initial value after the transmitting coil is turned off. Data are sampled at the same frequency at which the transmitter coil was driven (270 Hz, 225 Hz or 90 Hz). All data processing is done using Geosoft Oasis Montaj, with the exception of the GPS orientation and positioning data.

The position of each receiver is calculated based on the locations of two GPS antennae, one on the starboard side and the other on the port side of the helicopter. Data streams from both GPS antennae are post-processed using the base station data to provide improved positioning and orientation accuracy. The orientation of the aircraft is calculated from the relative GPS locations of the two antennae. The sensor locations are calculated based on this orientation and the GPS location of the antennae on the same side.

After converting the raw data to ASCII and importing into Geosoft, a low-pass filter is applied to remove helicopter rotor noise. A high-pass filter is subsequently applied to remove effects of aircraft motion, vibrations, and ground conductivity.

1.24 Target Selection for Detection

Data from the first two time gates were analyzed for noise properties and response characteristics over the calibration grid. The time gate with the strongest response and lowest overall noise is used to select anomalies. Anomalies were picked from the peaks of the gridded data, using a threshold based on the background noise levels for that data set. The list was edited to remove obvious artifacts and cultural sources (fences, etc). The final list was sorted based on amplitude.

Background noise is calculated as the standard deviation of the gridded data. In data sets such as EM and magnetic analytic signal that ideally have a zero-minimum value, the background noise is the value that responses must rise above to be considered anomalous. It is an aggregate of all noise achieved at the site, incorporating random and systematic sources such as the electronics, platform and local geology for the TEM-8 system. This value is unbiased by the number and amplitude of anomalies, unless the area is so contaminated that there is little or no background to be measured. The amplitude threshold used in anomaly selection is some multiple of this value and represents the minimum S/N of the anomaly list. The optimal threshold may vary depending on the size of the sample set (grid) and the distribution about the mode (geologic noise level). In benign geologies, a S/N of 2 may be acceptable. In other environments a S/N of 10 may be preferred. The area chosen to calculate the noise should be as large as possible, as long as

background conditions remain consistent.

1.25 Parameter Estimates

This demonstration is centered on detection capabilities of the airborne system. The target location is the only parameter being estimated from this data set. The target location is determined directly from the peak amplitude of the anomaly in the gridded data set. As such, the resolution is limited to the grid cell size. We have not used any inversion to estimate other target parameters.

1.26 Classifier and Training

The calibration line results are used to establish thresholds for anomaly selection and data filtering. EM anomalies were classified strictly by response amplitude, with anomalies thought to be caused by cultural features excluded. In order to understand how EM anomalies relate to magnetic anomalies, we determine, in areas where both data sets are available, the closest magnetic anomaly to a particular EM anomaly. If the EM and magnetic anomalies are spatially close enough to one another that they are likely to be produced by the same body, we assume this to be the case, and produce a scatter plot showing the amplitude of the magnetic anomalies plotted against the EM anomalies. We currently have no reliable method for discriminating fragments from intact ordnance using TEM-8 data.

1.27 Data Products

In this section, we provide summary data products for the report. High resolution maps have been provided to the ESTCP Program Office along with anomaly lists and Geosoft databases.

1.27.1 Test Grid Results

A test grid consisting of two parallel lines was established near the Double Eagle Airport, in an area that was within a few meters of the one used in the 2007 demonstration of the Battelle VG-16 and VG-22 systems (Battelle, 2008). Ordnance that was emplaced on the grid was provided by Battelle, Kirtland AFB, and USAESCH. USAESCH provided two 4.2-in mortars, a 105-HEAT round with tail, and a 105 mm projectile. Battelle provided two 81 mm mortars, a 105HEAT without tail, a 105 mm projectile, two 155 mm projectiles, two 60 mm mortars with tails, and M38s (one largely intact, one intact but without fins, a tail section, and a pair of primer caps). Four test items, unrelated to the ESTCP demonstration were provided by Kirtland AFB and emplaced in the grid. They included an 82 mm Russian projectile with tail, a 120 G round, an MK35, and a 155 FWD mortar. The test grid was flown daily, typically at the beginning of the survey day, and additionally was flown at a suite of altitudes. A representative plot of one of the test line surveys is provided in Figure 8.

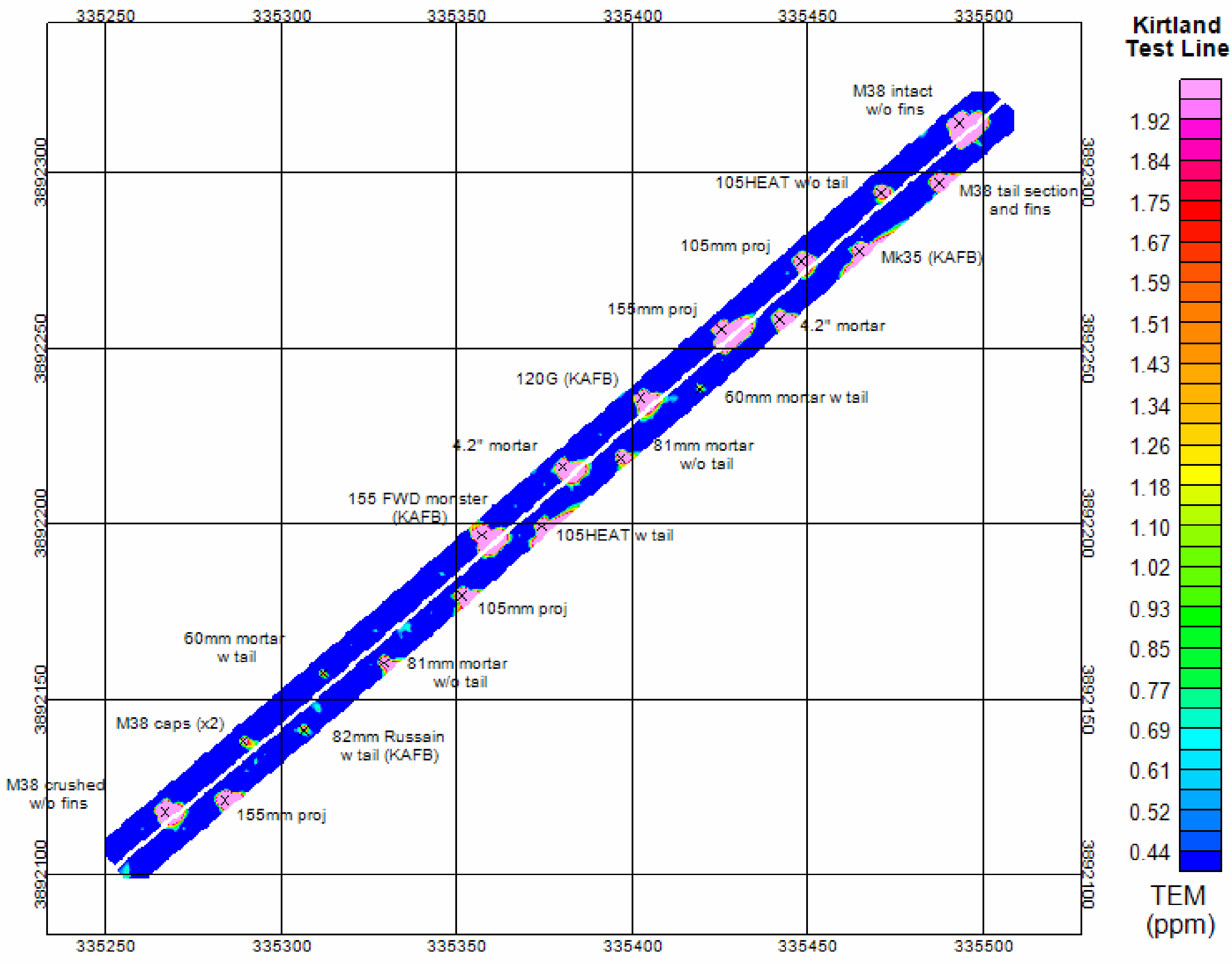

Figure 8. Representative map for the test grid at FKPBR.

Amplitudes of the anomalies associated with each of the test items for every test flight were compiled and plotted. These were used to assess representative amplitudes for each type of test item as a function of altitude. In turn, these amplitudes were used to select anomaly thresholds for data from the FKPBR and PBR-S12 sites. A summary plot of these data is illustrated in Figure 9.

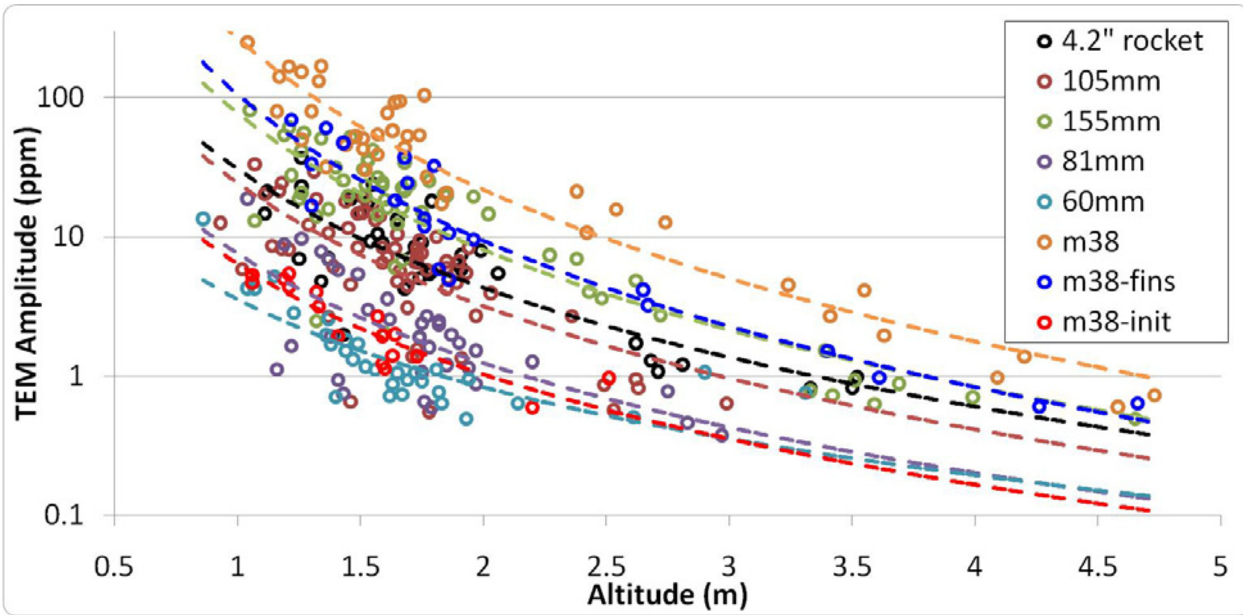

Figure 9. TEM-8 amplitude as a function of altitude for items in the test grid. Each point represents a measurement from a separate pass over each of the items, including the daily flyovers and a set of flights at selected altitudes that were conducted early in the field deployment.

1.27.2 FKPBR Results

The TEM-8 map of the FKPBR survey area is shown in Figure 10. The area surveyed encompassed a total of 617 acres. The N-3 target area (located at 330750 m East, 3893900 m North, UTM Zone 13N) and several of the nearby secondary targets are apparent to the northwest of the blind-seeded area (red box) in Figure 10. The density of anomalies falls off to the east and southeast of the N-3 target. Power line interference can be seen along the northern boundary.

An expanded view of the blind-seeded area at FKPBR is shown in Figure 11. This shows a general southeastward decay in anomaly density, presumably associated with the N3 target, along with some concentration of anomalies that are associated with the blind-seeded items.

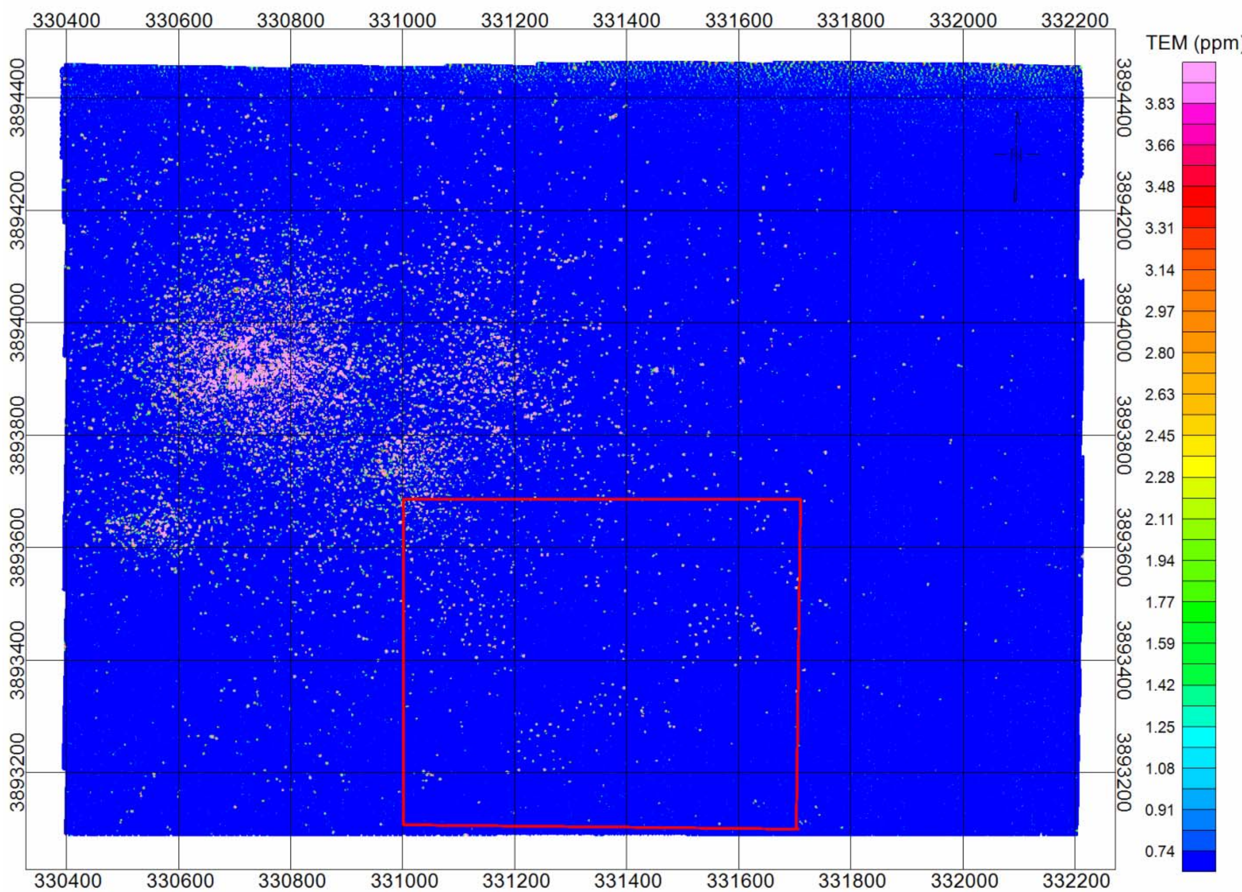

Figure 10. TEM-8 survey results from the FKPBR area. N-3 target area and two smaller target areas are shown northwest of the seeded area (red box).

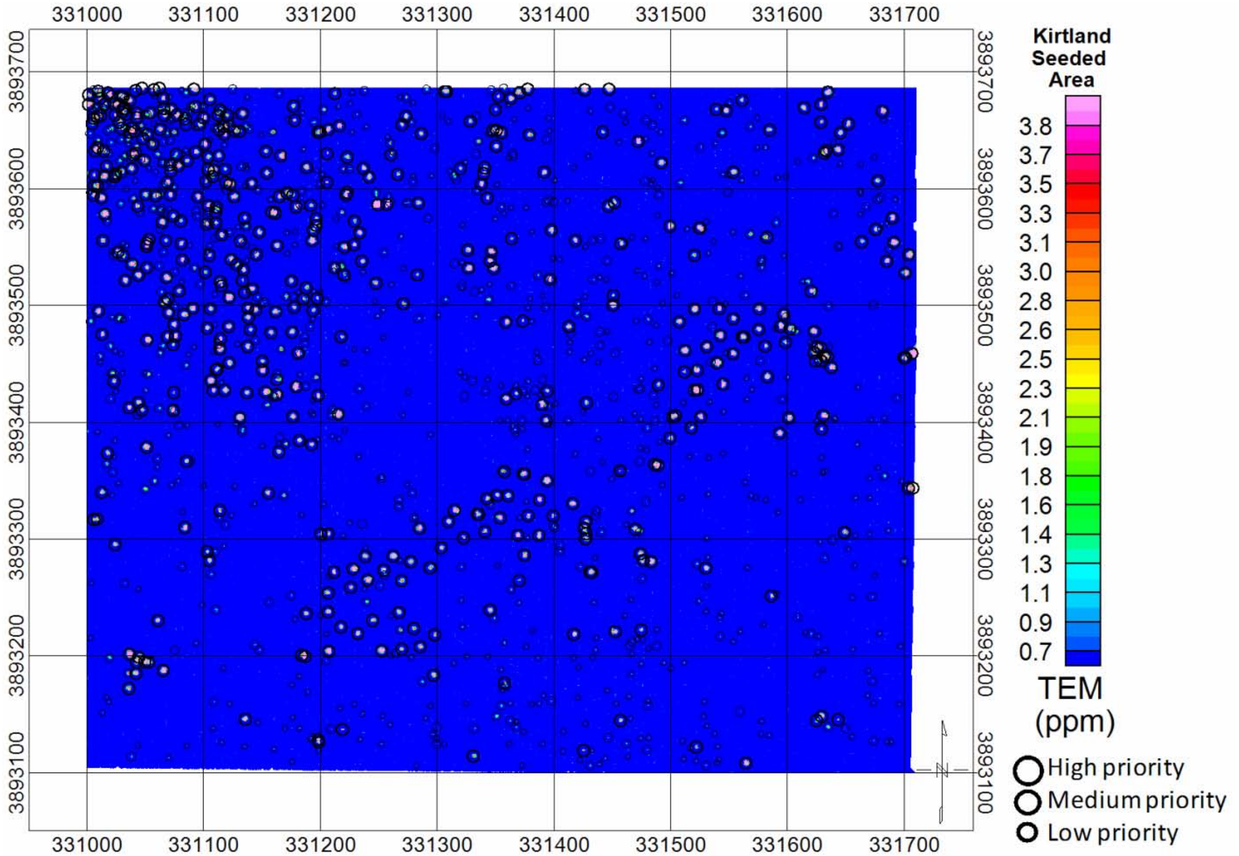

Figure 11 TEM-8 map of the blind-seeded area at FKPBR. The locations of items in the 'dig list' are divided into three categories, and are represented by a separate symbol for each category.

Based on the anomaly amplitudes for the four types of items emplaced in the blind-seeded grid, the anomalies were divided into three categories: A, B, and C. Types of ordnance that might cause anomalies in each amplitude category were projected based on these amplitude results. A total of 1,292 picks were submitted with 477 in the "A" category, 344 in the "B" category, and 471 in the "C" category.

Targets labeled as high priority on the map and "A" on the target list are represented by a large "O" and are 4.3 ppm and higher. This threshold should encompass nearly all of the 155 mm projectiles, 105 mm projectiles and 4.2" mortars, as indicated on Figure 14 below. Depth of burial is assumed to be less than 0.3 m, and if deeper could affect the breakdown of anomalies into the three categories described here.

Targets labeled as medium priority on the map and "B" on the target list are represented by a medium-sized "O" and are between 1.3 ppm and 4.3 ppm. This threshold is taken from the 105 HEAT and 81mm mortar anomalies on the calibration line. This group should include the majority of 81 mm mortars, some 105 HEATs, and a few 4.2" mortars.

Targets labeled as low priority on the map and "C" on the target list are represented by a small "O" and are below 1.3 ppm and above 0.9 ppm. However, we have done visual inspection and ranked some higher and some lower on the basis of the profile and map character. This threshold

is taken from the 81 mm mortar data and should include a portion of the 81 mm mortars as well as some portion of the larger ordnance items.

Average altitude from the laser altimeter within the 100 acre seeded test grid at FKPBR was 0.97 m. The mean sensor altitude within the same area was 1.3 m. The mean laser altimeter altitude from the entire 617 acre area was 1.23 m.

1.27.3 PBR S12 Results

The total area flown at PBR S12 was 444 acres. Before the survey began, it was noted that the study area extended beyond the edge of Mesa Lucero, so that a small portion of the proposed area could not be surveyed. To compensate for this, additional lines were flown along the northern boundary of the proposed area, ultimately leading to an 11 percent increase in the total survey area. The map view of the survey area is depicted in Figure 12. The edge of the mesa is apparent in the southeast quadrant of the map. An expanded view of the central portion of the target is shown in Figure 13.

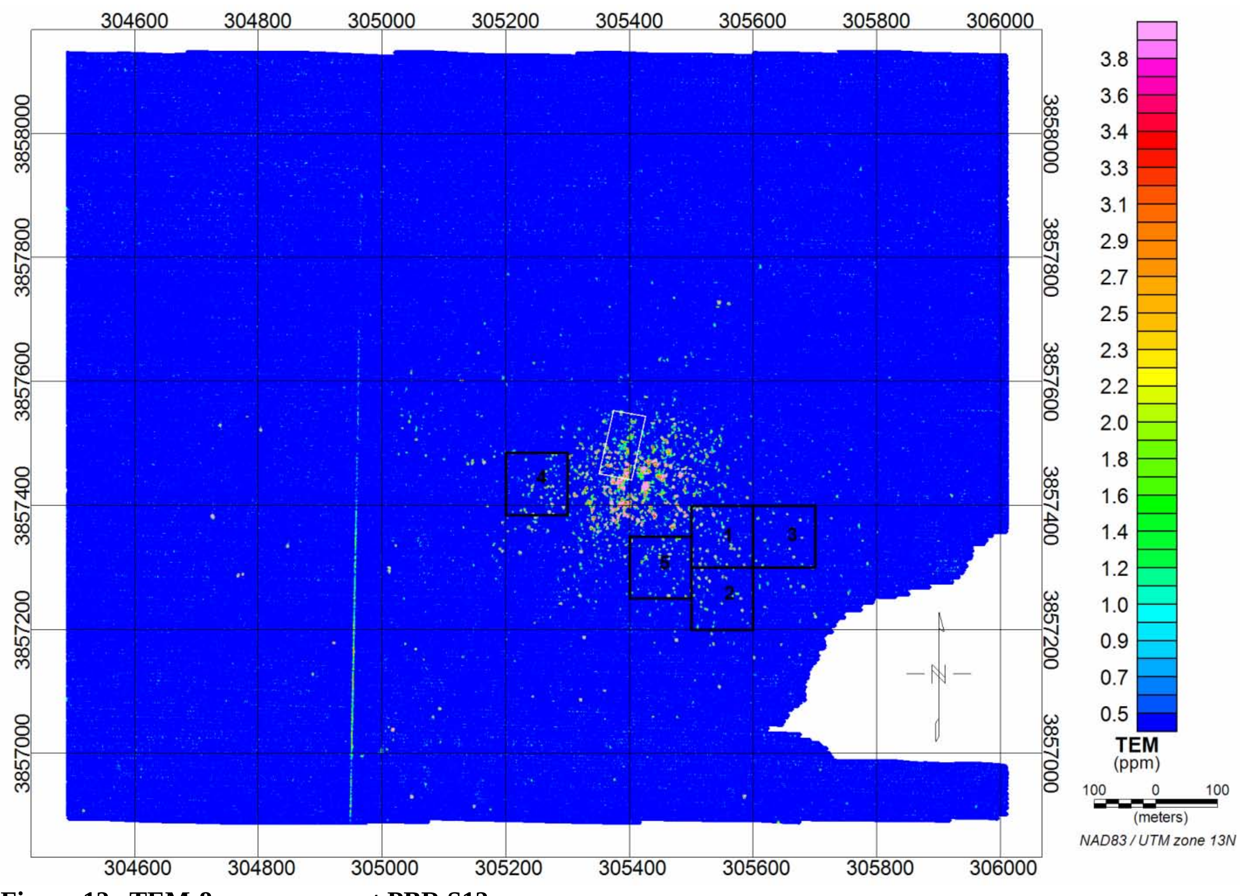

Figure 12. TEM-8 survey area at PBR S12.

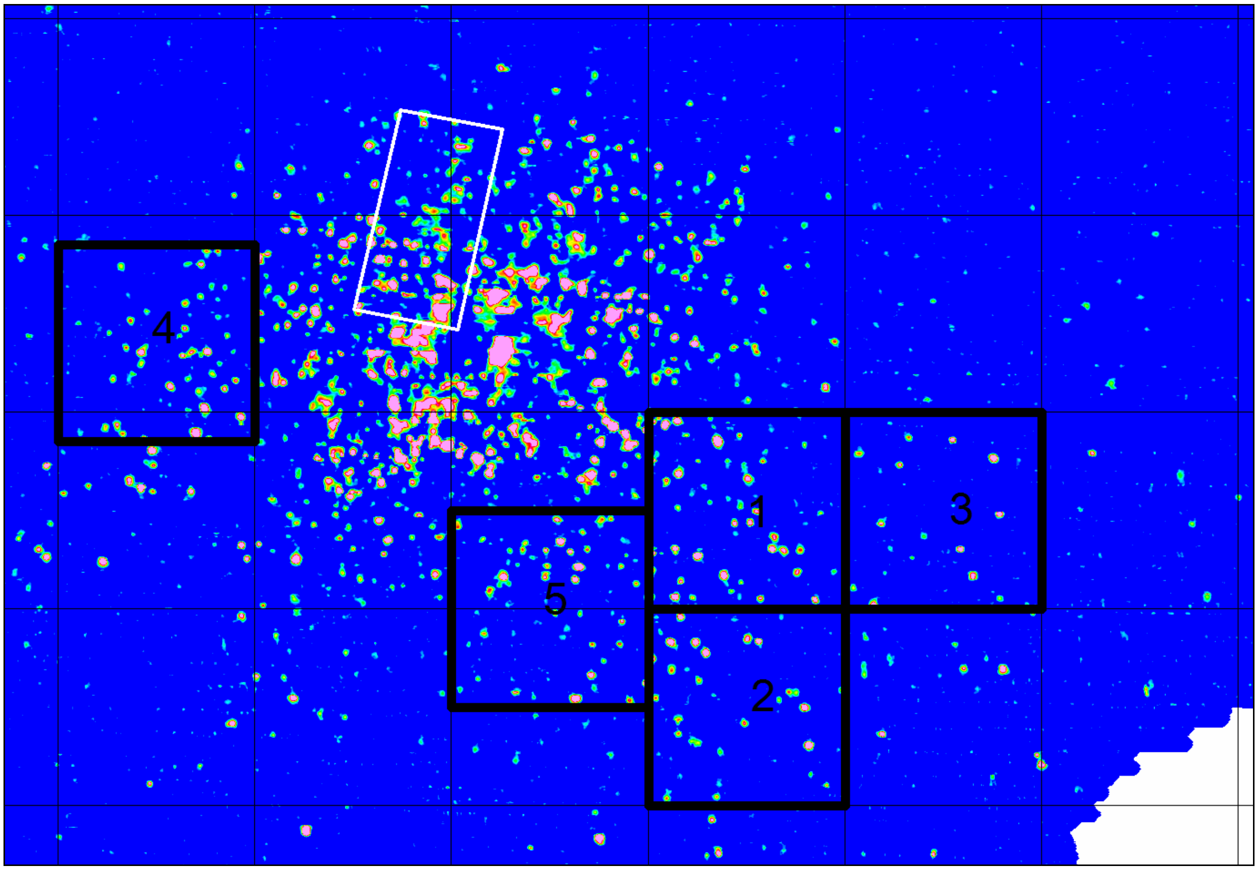

Figure 13: Portion of the TEM-8 results from the area surrounding the center of the target. The white rectangular box represents the Beep Mat validation area, and the five numbered black boxes represent candidate validation areas for follow-on EM61 surveys conducted as part of this project. Of these, Areas 1 and 4 were surveyed with EM61, followed by ground-truthing. Grid cells are 100 by 100 m.

Five areas were selected for possible ground-based mapping and validation, based on the airborne survey results. These five areas (numbered 1 through 5 on Figure 13) were chosen due to the modest number of large anomalies and because the overall density of Figure 13nomalies was lower than in the central target area, indicating that there were few overlapping anomalies in the data. From these five areas, AMEC selected two, Areas 1 and 4, for validation. Figure 16 shows the TEM-8 maps for these two areas.

Dig lists were prepared and are listed by dig priority. The dig priority is represented by different symbols in Figure 14. Thresholds for Grids 1 and 4 were selected on the basis of measurements of M38s and M38 scrap at the Kirtland Test Grid (Section 6.5.1). The priority "A" anomalies are considered high priority and are represented on the map with an "X". Circles are used to represent medium priority targets, which are also likely UXO fragments or MEC, and are appropriate for investigation. The "C" anomalies, represented by a "+" are thought to be predominantly noise. The thresholds between the A, B, and C categories are generally 2.15 and 1.08 ppm respectively, but after reviewing each anomaly, we have ranked some higher and some lower on the basis of their profile and map character. A lower bound of 0.65 ppm was placed on the "C" anomalies.

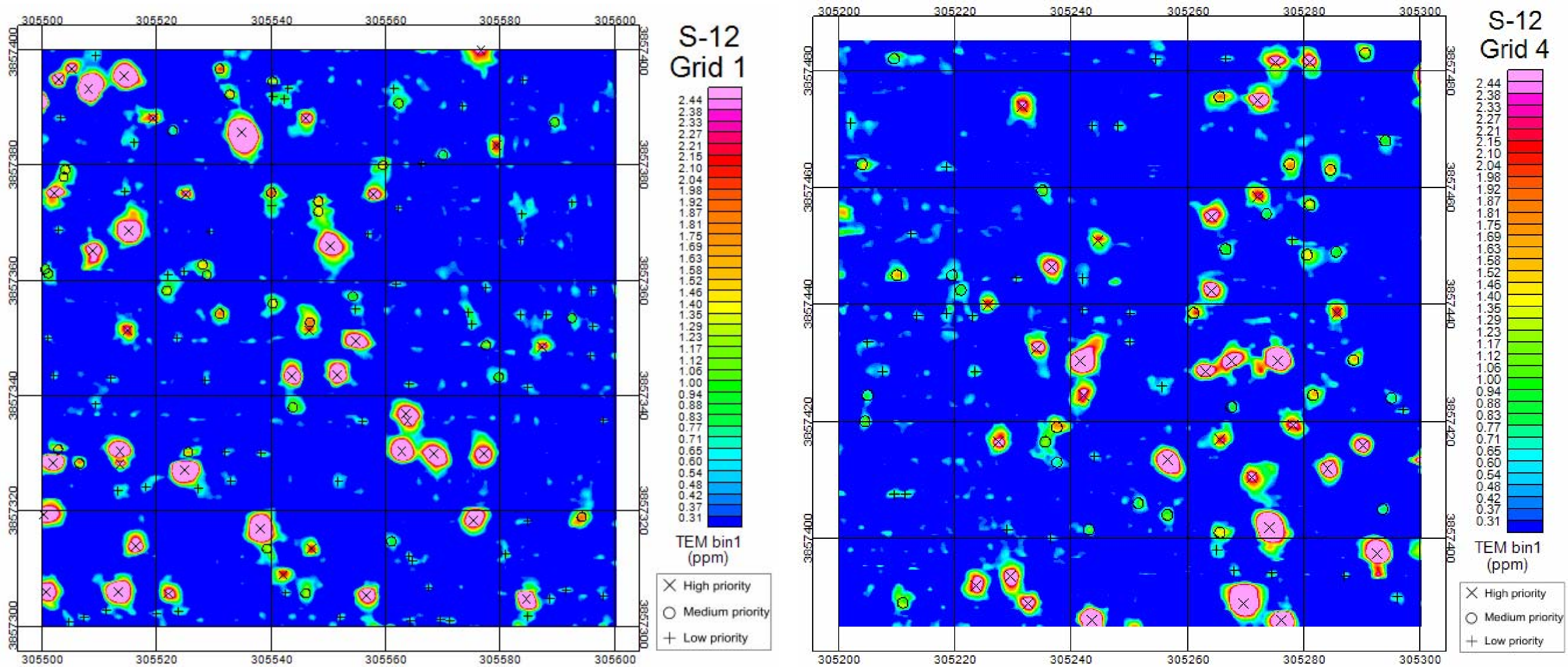

Figure 14 TEM-8 maps for Validation Grids 1 and 4. Symbols on the maps are associated with anomalies picked for three different ranges of amplitudes.

Anomalies for the S-12 validation areas are provided in Appendix B. The total number of anomalies selected in each of the three categories is listed in Table 6-1.

Table 6-1: Numbers of anomalies picked for each of the 5 validation areas at PBR S12.

Area	Priority A	Priority B	Priority C	Total
1	41	33	62	136
2	24	22	60	106
3	13	18	70	101
4	34	40	52	126
5	36	44	55	135

The mean altitude at the S-12 survey site as a whole was 3.73 m. In the north, altitudes tended to be higher due to vegetation (Figure 15). Mean altitudes from the laser altimeter for the five validation grids only are provided in Table 6-2. Mean sensor altitudes are generally about 0.3 m higher than the laser altitudes. An altitude map for the study area at S-12 is shown in Figure15.

Table 6-2: Laser altimeter-derived mean altitudes for the five S-12 validation areas.

Area	Mean Altitude *(m)*
1	2.016
2	2.099
3	2.050
4	2.094
5	2.049

m = meters

In addition to these five candidate validation areas, Figure 15 depicts a related study area measuring 50 by 100 m, where validation digs were conducted by USAESCH for the Army Environmental Center (AEC). This area, previously outlined in Figure 10 and Figure 11 was used by Battelle to assess a new ground-based instrument (Beep Mat) for AEC. Battelle staff acquired both EM61 and Beep Mat data within that area (Figure 16 and 17). Anomalies were chosen for validation from both EM61 and Beep Mat data sets. There were a total of 100 anomalies selected for validation from a July 2006 EM61 survey and a December 2007 Beep Mat survey (Battelle, 2008). The locations of these anomalies are shown in Figure 16.

The airborne map for the Beep Mat area is shown in Figure 17 with the anomalies selected for the AEC study superimposed. Highly concentrated anomalies in the ground-based maps often combine to form large, diffuse, irregularly-shaped airborne anomalies, particularly in the southern half of the map area.

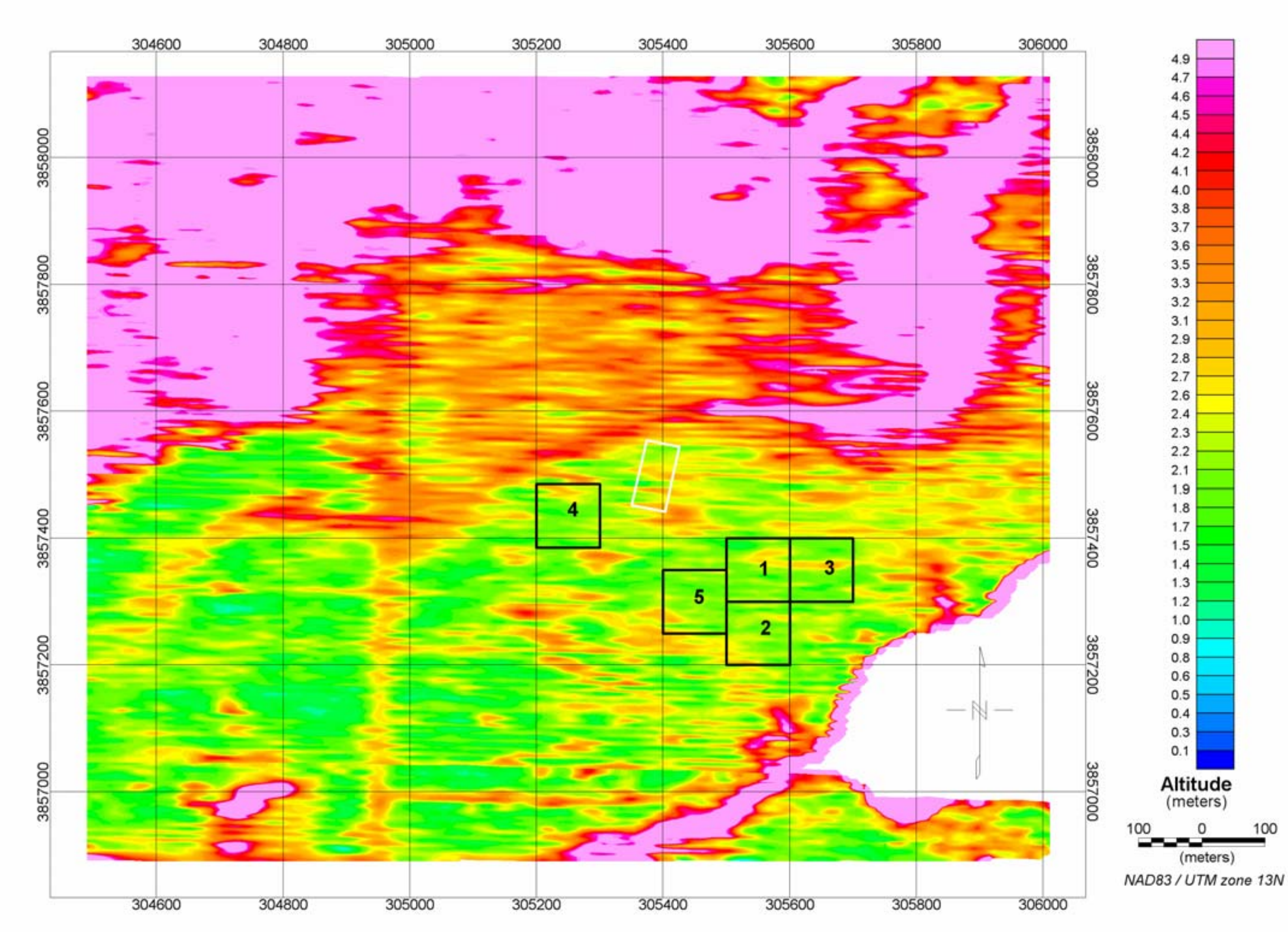

Figure 15. Altitude map of the entire S-12 study area. Note higher altitudes in tree-covered areas in the north, and a linear north trending feature associated with a fence in the western half of the study area.

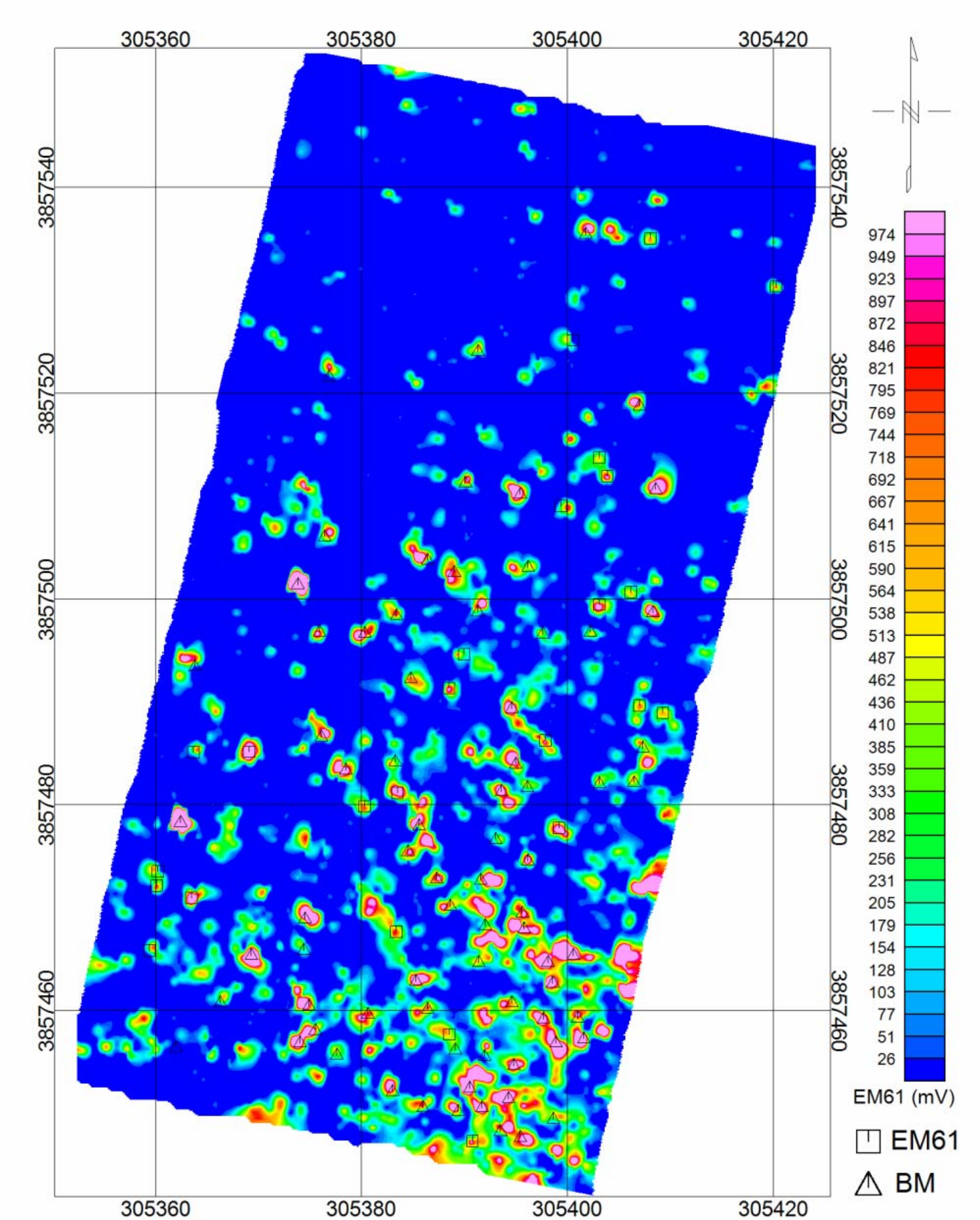

Figure 16. Anomalies at S-12 selected for validation by the USAESCH contractor for AEC. Seventy five anomaly picks were derived from Beep Mat data while the remaining 25 were derived from EM61 data. Validation of these anomalies was deferred until after the airborne data were acquired at S-12. This allowed the dig results to be extended to the TEM-8 analysis.

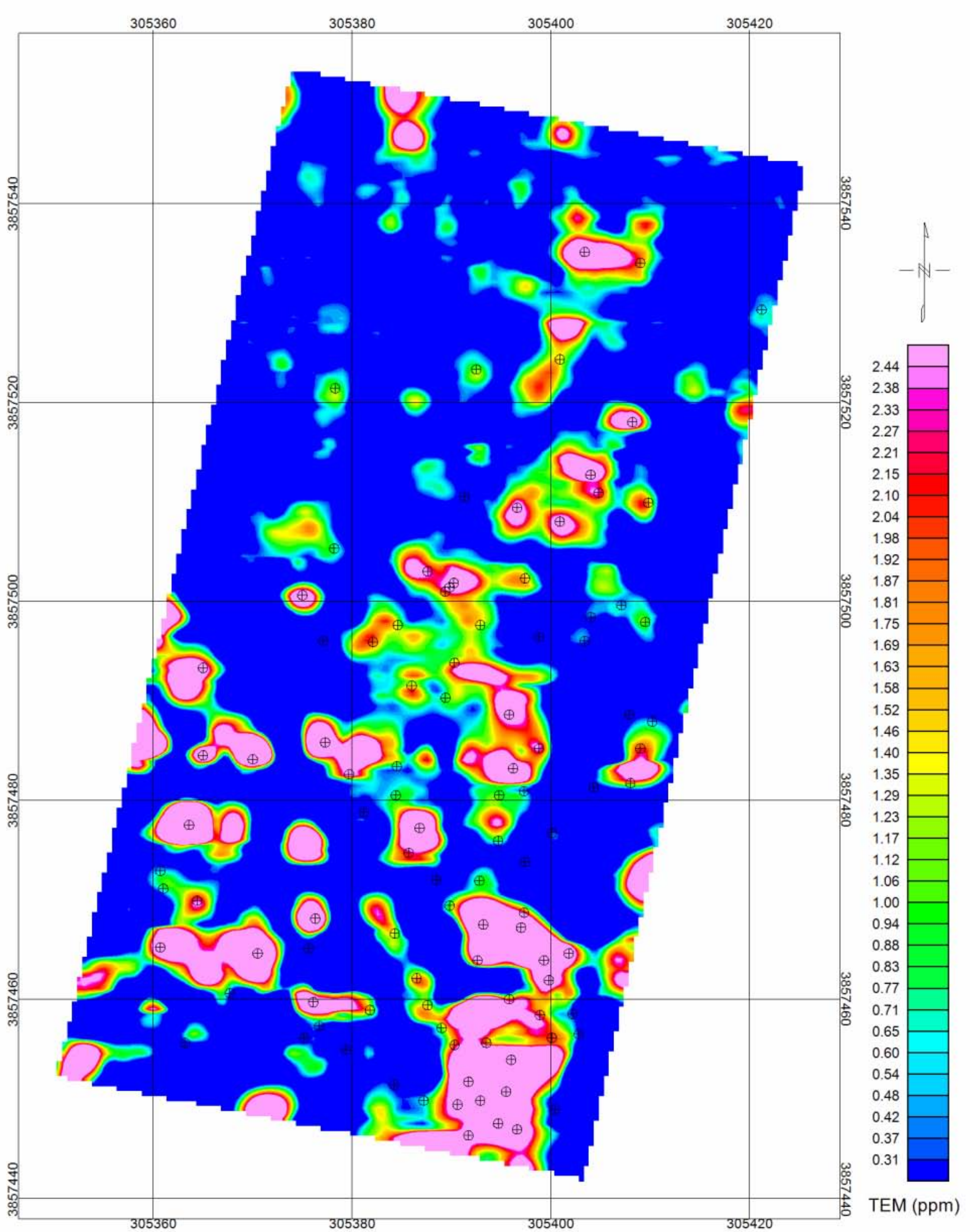

Figure 17. TEM-8 results for the Beep Mat validation area. Locations of the anomalies validated with AEC funding are shown.

1.27.4 Archived Data Products

We include the following data products in Appendix C:

- Lists of EM anomalies ordered by the amplitude of either EM channel 1 or 2. The list includes surface position (datum: NAD83, UTM Zone 13N) and anomaly amplitude (X, Y, AMPL);
- Geosoft databases of final processed EM data containing positional information, survey height, and amplitude of response for the significant time gates;
- Geosoft maps gridded from the database information for the time gate used to make the ordered anomaly list;
- Excavation data for each of the surveyed areas. These data include positional and orientation data for the item, and a description of the item.

PERFORMANCE ASSESSMENT

Effectiveness of the demonstration is determined from comparisons of the processed and analyzed results from the demonstration survey and the established ground-truth. Some qualitative parameters may be judged against results of previous airborne and ground-based surveys at FKPBR and elsewhere. Evaluation of seeded items provides a basis for assessing detection of small ordnance items. These comparisons include both the quantitative and qualitative items described in this section, which are documented fully in project reports available from ESTCP. Demonstration success is defined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in Section 3.1. Methods utilized by Battelle on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters (e.g. GPS, magnetometer operation, data recording, system compensation measurements, etc.) in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Data collection occurred at the specified flight altitudes over the various test areas. Table 3-1 identified the expected performance criteria for this project, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative).

1.28 FKPBR Seeded Area

After the AMEC / Battelle team submitted the target list to ESTCP for the FKPBR seeded area, the Institute for Defense Analysis (IDA) conducted a comparison of the lists with the actual locations of seed items. In all, 110 items were emplaced in the 100-acre grid. Validation results compiled by IDA are listed in Table 7-1.

Table 7-1: Dig Results for the Blind-seeded area at FKPBR (mean and standard deviation of miss distances in meters)

Halo Radius	UXO Type	Total # Seeds	# Seeds Detected	Pd	Mean *(Xi)*	Mean *(Yi)*	Std Dev *(Xi)*	Std Dev *(Yi)*	Mean *(miss dist)*	Std Dev *(miss dist)*
0.5 m	All UXO	110	87	0.79	0.02	0.00	0.22	0.16	0.24	0.13
0.5 m	105 mm P	8	5	0.63	-0.14	0.03	0.18	0.06	0.18	0.14
0.5 m	4.2"	52	38	0.73	0.03	0.02	0.21	0.19	0.25	0.12
0.5 m	155 mm P	24	22	0.92	0.07	-0.02	0.22	0.11	0.22	0.11
0.5 m	81 mm M	12	9	0.75	0.06	0.03	0.29	0.19	0.29	0.19
0.5 m	105H	14	13	0.93	-0.06	-0.04	0.19	0.19	0.25	0.10
1 m	All UXO	110	108	0.98	0.09	-0.02	0.35	0.17	0.33	0.22
1 m	105 mm P	8	8	1.00	0.22	-0.04	0.52	0.11	0.42	0.37
1 m	4.2"	52	50	0.96	0.14	-0.01	0.34	0.20	0.35	0.21
1 m	155 mm P	24	24	1.00	0.02	-0.01	0.28	0.11	0.25	0.15
1 m	81 mm M	12	12	1.00	-0.02	0.01	0.43	0.18	0.38	0.24
1 m	105H	14	14	1.00	0.01	-0.04	0.33	0.18	0.30	0.22
1.5 m	All UXO	110	109	0.99	0.09	-0.02	0.36	0.17	0.34	0.23
1.5 m	105 mm P	8	8	1.00	0.22	-0.04	0.52	0.11	0.42	0.37
1.5 m	4.2"	52	51	0.98	0.16	-0.02	0.36	0.20	0.37	0.23
1.5 m	155 mm P	24	24	1.00	0.02	-0.01	0.28	0.11	0.25	0.15
1.5 m	81 mm M	12	12	1.00	-0.02	0.01	0.43	0.18	0.38	0.24
1.5 m	105H	14	14	1.00	0.01	-0.04	0.33	0.18	0.30	0.22

M = mortar, P=projectile , h=howitzer, Std Dev = standard deviation, miss dist = miss distances in meters, Xi = easting offset in meters, Yi = northing offset in meters, m = meters, mm=millimeters, Pd = probability of detection, ‘ = inches

1.28.1 Detection

The performance results demonstrate that the TEM-8 system was successful in detecting 109 out of the 110 seed items for a 1.5 m search radius and 108 out of 110 for a 1 m search radius. The one missed item was a 4.2-in mortar which was 1.51 m from the nearest item on the dig list. The amplitude response of the seed items was larger than anticipated from the test grid. All but four of the seeded items had amplitudes in the "A" category, exceeding 4.3 ppm. The other four items were all in the "B" category, and all had amplitudes exceeding 1.3 ppm. The amplitude variance is thought to be related to the nature of flights over the test grid. Although test items were detected in flights over the test grid, there was often an offset between sensors and targets, resulting in lower measured amplitudes. Such offsets do not occur when the system is conducting a full density survey.

All of the 109 detected test items were among the first 565 listed on the prioritized dig list. The remaining 727 anomalies on the dig list, categorized as "False positives" on the pseudo-ROC curve, are of unknown origin. Because the 100-acre blind-seeded area lies within 300 m of the center of the N3 target and overlaps some of the previously-identified ancillary targets, it is probable that a large portion of these 727 anomalies are also ordnance related. This cannot be determined without intrusive validation. A pseudo-ROC curve for the FKPBR is provided in Figure 18.

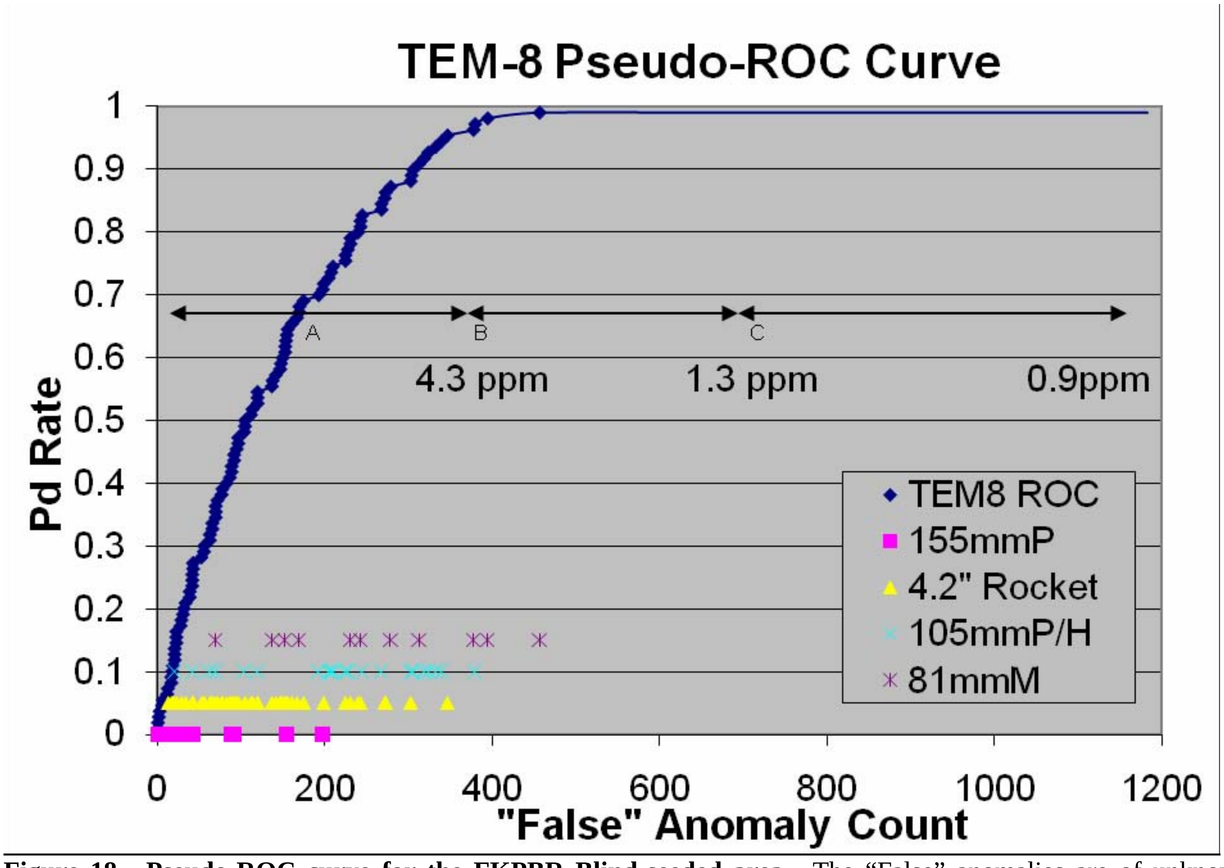

Figure 18. Pseudo-ROC curve for the FKPBR Blind-seeded area. The "False" anomalies are of unknown origin, and given site conditions, it is very likely that many of them are ordnance-related.

1.28.2 Positional Accuracy

Positional accuracy for the FKPBR site was much better than required, based on the guidelines established in advance of the survey (Figure 19). The missed 4.2" mortar is included in this figure for completeness, near the eastern axis of the plot at 1.51 m offset, 1 cm from inclusion as a "hit". The positioning errors are clearly skewed in an E-W direction, perpendicular to the flight path. This is likely attributed to the larger sample interval in that direction, determined by the receiver coil spacing, whereas the on-line measurements occur at intervals of approximately 0.1 m.

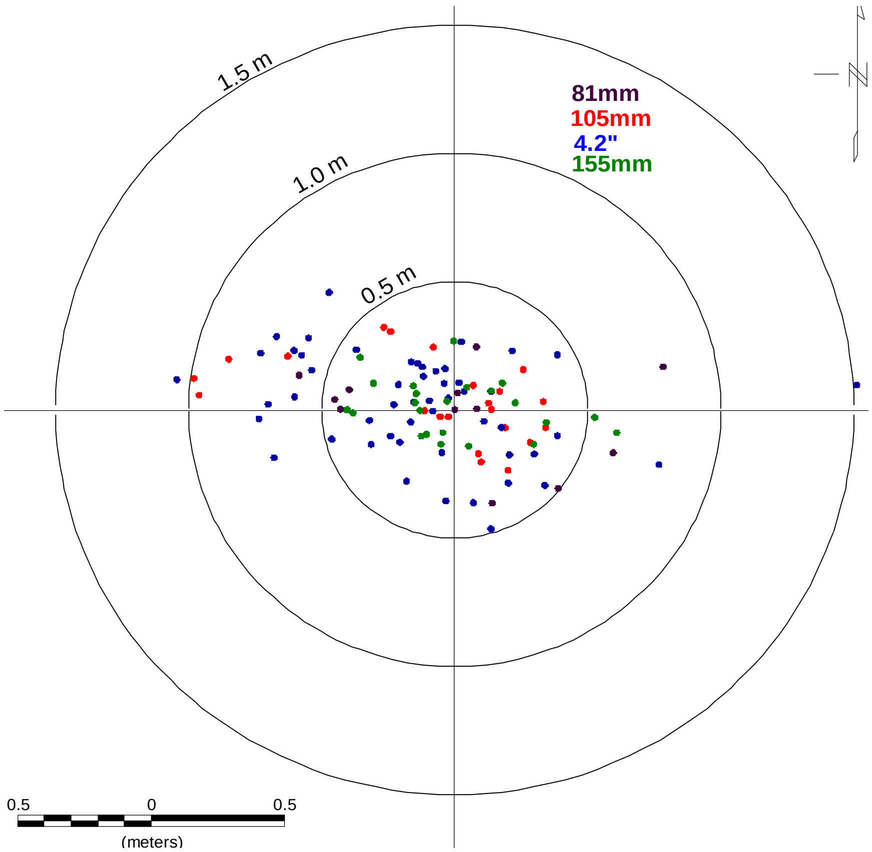

Figure 19. Positional accuracy for the FKPBR blind-seeded targets.

1.28.3 Noise Assessment at FKPBR

A comparison of TEM-8 S/N with airborne magnetometer S/N was performed, using grids from the TEM-8 data and 2005 Sky Research "Helimag" data provided by ESTCP. For both data sets, the two areas shown as shaded rectangles in Figure 20 were chosen for assessment. The western area was selected as representative of a quiet magnetic environment, while the eastern block was representative of a noisier magnetic environment. There are no blind-seeded anomalies within either block. The average signal in the entire 600-acre area was estimated by taking the average of the peak of 770 coincident anomalies (within 1 m) picked from the Helimag and TEM-8 gridded data. The standard deviation of the profile data was calculated within each of the blocks

for both data sets to provide a measure of noise. Noise measures were similar for the TEM-8 data in the two blocks, but varied by a factor of about 5 for the magnetometer data (Table 7-2). Overall, the TEM-8 exhibited a SNR of 0.81 times that of Helimag in the quiet area and 4.0 times that of Helimag in the noisy area.

Magnetometer data were also acquired in 2009 with the seed items present at the FKPBR site for ESTCP by Sky Research (D. Wright, UXO Forum 2009). The results of that survey are not presented here, but should be available in other ESTCP reports and in UXO Forum online presentations.

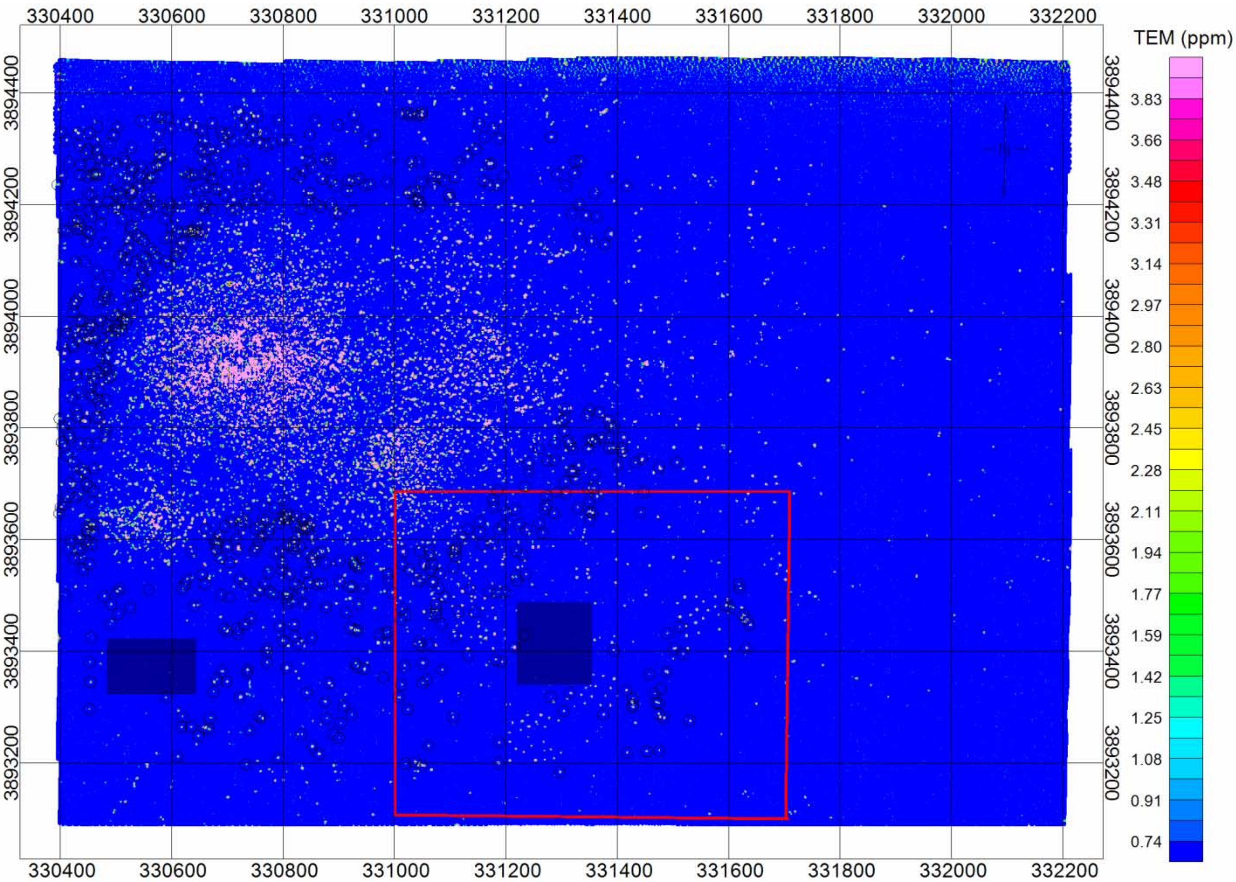

Figure 20. Noise assessment areas at FKPBR

Table 7-2. SNR estimates for the FKPBR study area.

	TEM-8-West	TEM-8 East	Helimag West	Helimag East
Estimated Noise	0.26 ppm	0.29 ppm	1.27 nT/m	6.78 nT/m
Estimated Signal	11.27 ppm	11.27 ppm	66.81 nT/m	66.81 nT/m
SNR	42.67	39.31	52.48	9.86

Ppm = parts per million
nT/m = Nanoteslas per meter

1.29 PBR S12 Validation

1.29.1 EM61 Data and Selection of Anomalies for Validation

Based on the TEM-8 data, EM61 data were acquired in Grids 1 and 4 at PBR-S12. These results are shown in Figure 20 and Figure 21.

EM61 anomalies were picked in three groups, selected to correlate with the three TEM-8 categories. The three groups were based on measured TEM-8 and EM61 results from the calibration grid (Table 7-3). The EM61 results represent a standard EM61-MK2, bottom coil, gate 1. The resulting threshold conversions, based on these measurements, are provided in Table 7-4

Table 7-3: TEM-8 and EM61 anomaly amplitudes for calibration items

	Target	Measured EM61 response to surface target *(mV)*	Estimated EM61 response to target at 50 cm depth *(mV)*	Average TEM8 bin1 response to surface target from 2 m alt *(ppm)*	Conversion factor between EM61 and TEM8 for surface targets	TEM8 bin1 response to target at 50 cm depth from 2 m	Conversion factor between EM61 and TEM8 for buried targets
1	M38 w/o fins	12262	383	28.86	425	12.50	30.7
2	M38fins	9962	311	9.38	1062	4.30	72.5
3	105H w/o tail	2226	70	3.78	590	1.93	36.0
4	Mk35	5336	167	5.90	905	2.86	58.4
5	105 mm	2777	87	3.81	728	1.40	62.1
6	4.2"	4093	128	5.63	728	2.58	49.6
7	155 mm	11820	369	12.59	939	5.76	64.1
8	60 mm w tail	211	7	0.44	474	0.18	36.2
9	120 mm	3678	115				
10	81 mm w/o tail	976	31	1.35	724	0.55	55.2
11	4.2"	4291	134	3.81	1125	1.75	76.8
12	105H w tail	3068	96	2.97	1034	1.22	78.9
13	155 mm FWD	12192	381	9.53	1279	4.37	87.3
14	105mm	3676	115	3.21	1146	1.39	82.7
16	81 mm w/o tail	921	29	1.35	683	0.55	52.1
17	60 mm w/ tail	251	8	0.65	388	0.33	23.7
18	82 mm Russian	542	17	0.88	615	0.38	44.3
19	M38 initiators	273	9	0.96	284	0.52	16.4
20	155mm	8565	268	8.09	1059	4.14	64.6
21	M38 w/o fins	12444	389	16.78	742	7.68	50.6
	AVERAGE				**786**		**54.8**

ppm = parts per million, mV = millivolts, H = XX, mm = millimeters, FWD = fired without detonation

Table 7-4: Threshold values for TEM-8 and equivalent thresholds for EM61

Anomaly Group	TEM-8 amplitude range	EM61 equivalent range
A	> 2.16 ppm	> 100 mV
B	1.08-2.16 ppm	40-100 mV
C	< 1.08 ppm	< 40 mV

ppm = parts per million, mV = millivolts

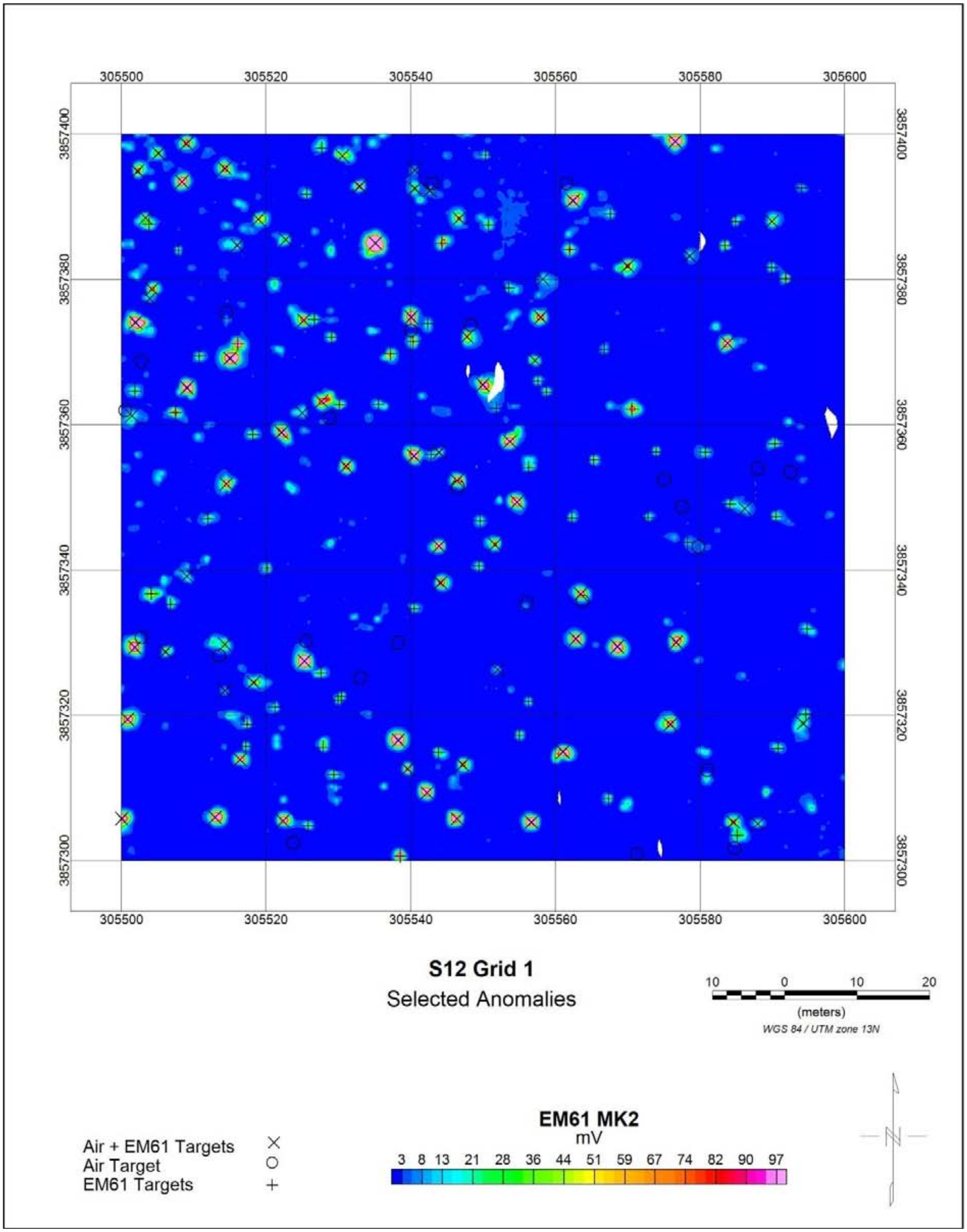

Figure 20. EM61 map of Grid 1 at PBR-S12

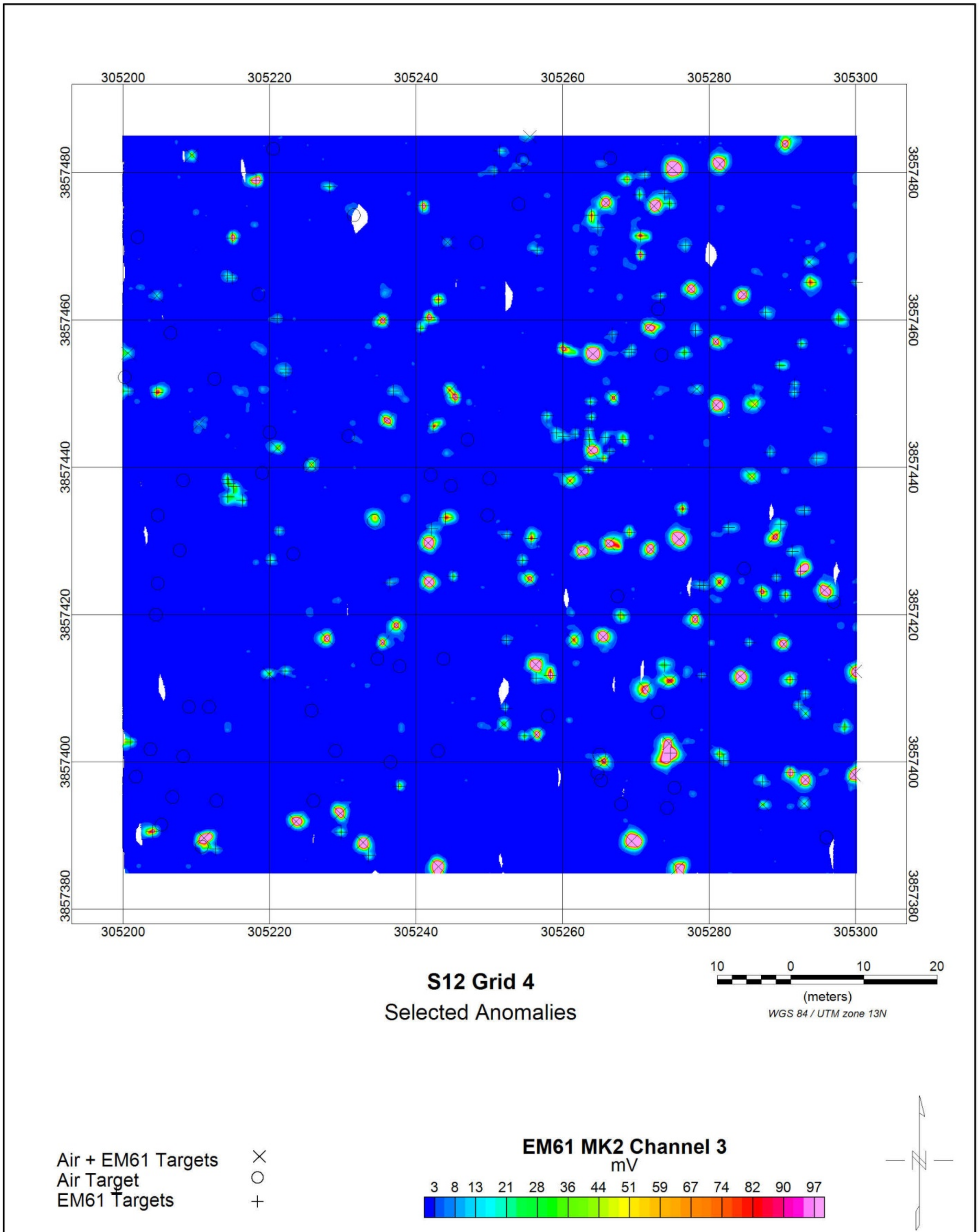

Figure 21. EM61 map of Grid 4 at PBR-S12

1.29.2 Detection Results

From the EM61 surveys, 222 anomalies were picked in Grid 1 and 180 anomalies were picked in Grid 4 (Table 7-5). From the two lists, all of the TEM-8 Category “A”, most of the “B” anomalies and half or more of the “C” anomalies were selected for excavation (Table 7-5). Total number of digs in Grid 1 was 168 (EM61 Digs + TEM-8 Digs – Overlap), and in Grid 4 was 157. These are tabulated in Table 7-5. All of the EM61 anomalies in both grids yielded detections; fourteen of the TEM-8 digs in Grid 1 and 22 in Grid 4 yielded false positives. Figure 22 shows the breakdown of TEM-8 performance for all excavated anomalies (whether selected from TEM-8 or EM61 dig lists) by weight. All but two of the excavated items over 5 lb were detected by TEM-8, and 78 percent of the excavated items weighing between 1 and 5 pounds were detected. TEM-8 detected 31 percent of theM38 frag which weighed less than 1 lb. The locations of items in different size classes are shown on Figure 23 and Figure 24, superimposed on the TEM-8 anomaly map, along with the location of false positives (identified as “empty” and anomalies that were detected by EM61 but not included on the TEM-8 dig lists. Table 7-6 shows the breakdown of detected items by some of the more common anomaly types, including “mostly intact M38s”, nose cones, initiators, and wire. Photographs of the excavated items are provided in Appendix C.

Table 7-5: Dig Results for PBR S12 Grids. TEM-8 picks are further divided in to the A, B, and C categories. Numbers of anomalies picked by both EM61 and TEM-8 are listed as “overlap”.

	Source	Picks	Digs	Detects
Grid 1	**EM61**	**222**	**143**	**143**
	TEM-8	**136**	**100**	**86**
	TEM-8 A	41	41	39
	TEM-8 B	32	32	28
	TEM-8 C	63	27	19
	Overlap	**77**	**75**	**75**
Grid 4	**EM61**	**180**	**129**	**129**
	TEM-8	**126**	**93**	**71**
	TEM-8 A	34	34	34
	TEM-8 B	39	39	31
	TEM-8 C	52	20	6
	Overlap	**69**	**66**	**66**

Table 7-6. Summary of targets detected by EM61 and TEM-8

	Excavated	Detected by EM61	Detected by TEM-8
Mostly Intact M38	38	37	36
Nose cone	46	45	34
Initiator	42	41	6
2" band	22	21	4
Wire	6	6	0

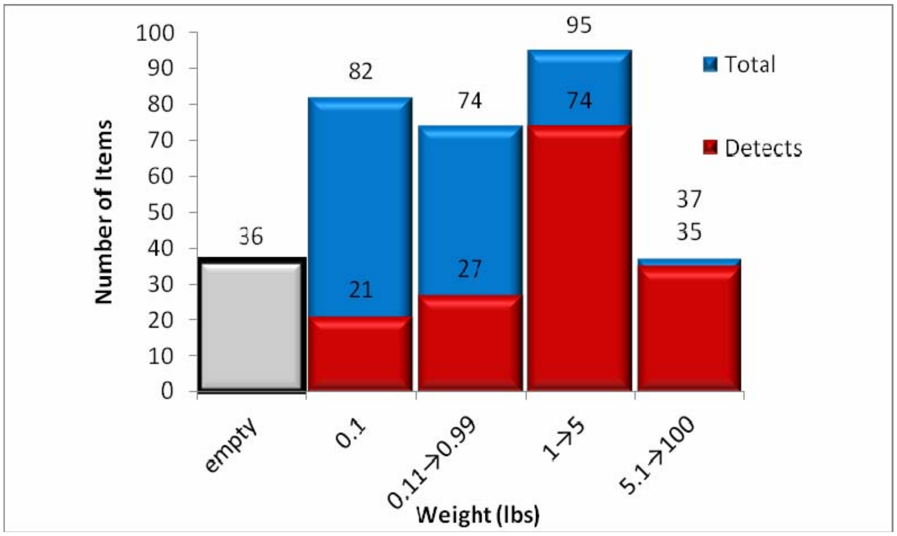

Figure 22. Graphical representation of the distribution of detects to total picks as a function of weight. Four weight ranges are shown, and these are clearly not linear in the range of weights. Detection falls off sharply for items smaller than one pound, but it is noteworthy that some of the low mass items are even detected.

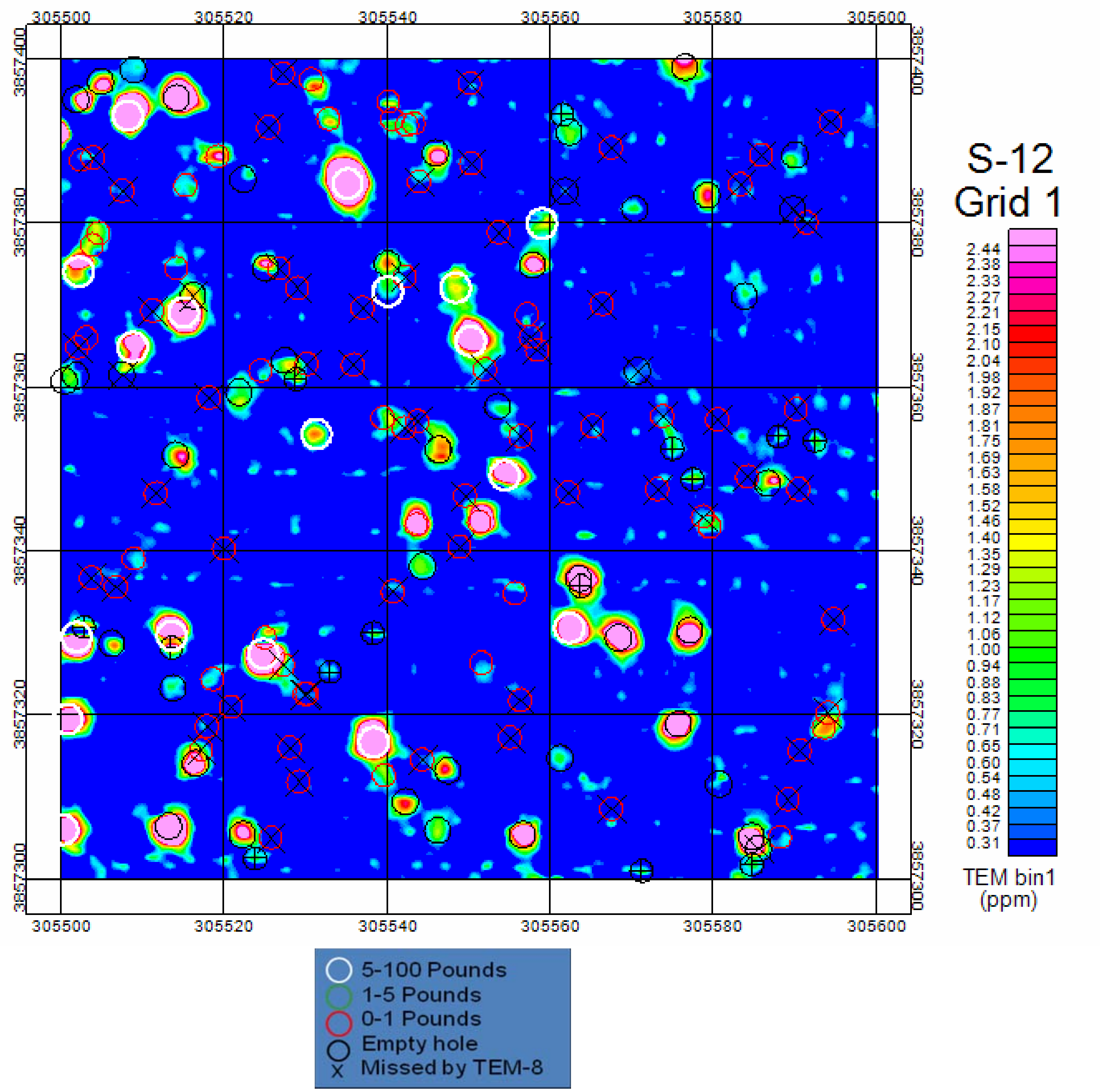

Figure 23. Grid 1 dig summary by weight.

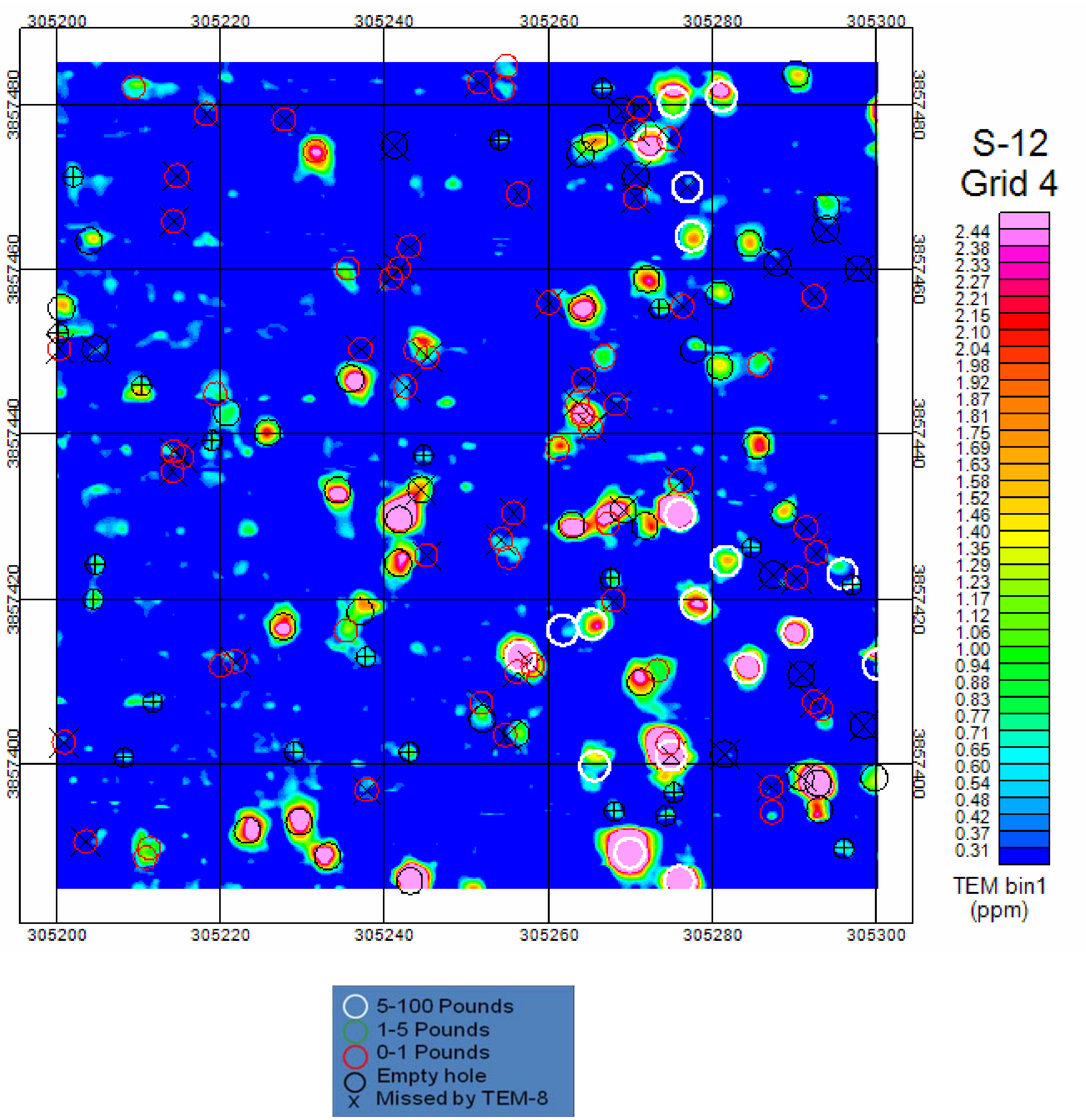

Figure 24. Grid 4 dig summary by weight.

1.29.3 Positional Accuracy

The positional accuracy of the TEM-8 system at PBR-S-12 is shown in Figure 25. The mean miss distance for successful digs associated with TEM-8 anomalies was 0.58 m with a standard deviation of 0.34 m. There were two digs outside of the 1.5 m search radius. The distribution of positioning errors for PBR-S12 is not skewed the way it was for FKPBR (see Figure 19). This difference is not fully understood, but could be related to the way in which the locations of excavated targets were measured, the accuracy of positioning for those items, or some other factor(s). The distribution is not as tight as it was for FKPBR, and the mean error and standard deviation are somewhat larger than at FKPBR.

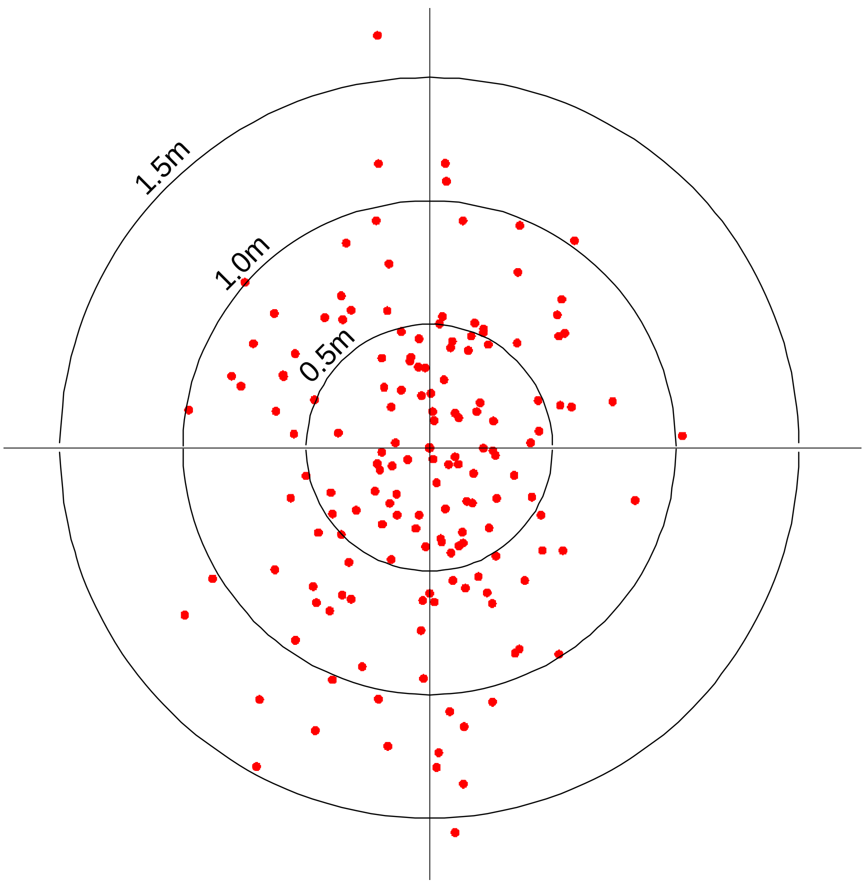

Figure 25. Positional errors for PBR-S12 validations.

1.29.4 Beep Mat Validation Results

The airborne data were compared with validation results for the 100 locations selected from ground-based data for excavation (Battelle, 2008b). Of these, 75 were derived from the Beep Mat results and 25 were derived from the EM61 data. None of the excavations were selected from airborne data (see Table 7-6). Overall, only 67 percent of the 100 Beep Mat validation digs had corresponding TEM-8 anomalies, using a search radius of 1.5 m. In general, we attribute this to the fact that the Beep Mat study area was close to the center of the target area and has a high concentration of anomalies. From Figures 19 and 20, it is apparent that in many cases several EM61 anomalies combine to form large TEM-8 anomalies. In these cases, the location

of the grouped TEM-8 anomaly would be outside of the search radius for actual items. To evaluate this effect, we reviewed the data to separate airborne anomalies that appeared to be associated with groups of EM61 anomalies. These are tabulated as a separate column in Table 7-7. When these are removed, overall detection rises to 89 percent. Figure 26 illustrates the effects of grouping in anomaly detection in this area. The TEM-8 performance is best when considering only anomalies that had an EM61 response, or both EM61 and Beep Mat responses (Table 7-7).

Table 7-7. Validation results from Beep Mat excavations

	No. Digs with hits	**No. of TEM-8 hits**	**Raw Detection %**	**No. Missed** *(due to grouping)*	**Detect % (***without grouped)*
Total	100	67	67	25	89
EM61 only	25	19	76	5	95
BM* & EM61	21	14	67	6	93
All EM61	46	32	70	11	91
All BM	75	48	64	20	87
BM only	54	34	63	14	85

*BM = Beep Mat

The validation results from the Beep Mat area are less detailed than those conducted by AMEC at Grid 1 and Grid 4. Actual locations of items are not thoroughly documented, and the excavated items are not described in as much detail. In general, once the effects of grouping are removed, the validation in the Beep Mat area yields similar Pd results to those in the other two areas.

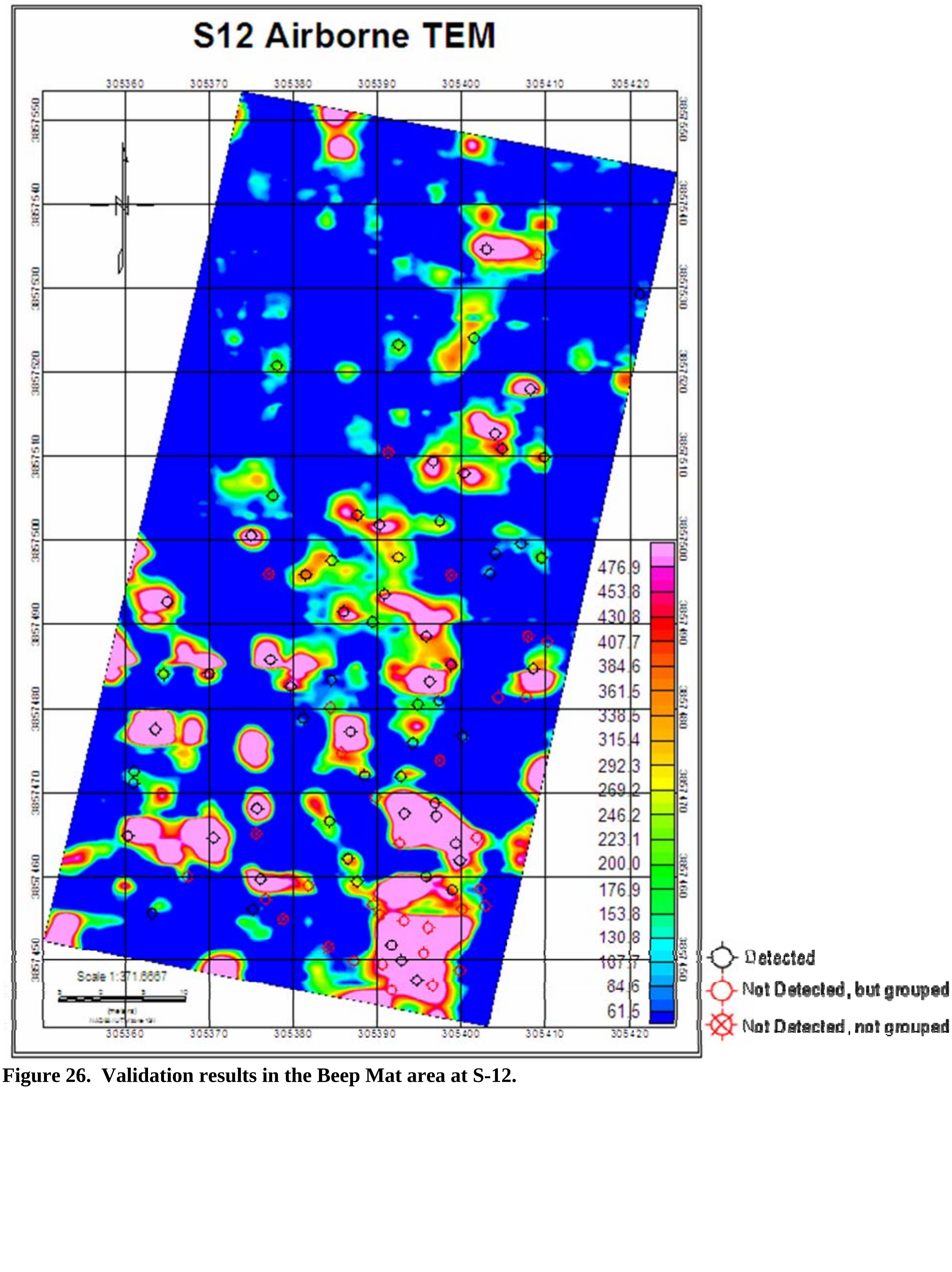

Figure 26. Validation results in the Beep Mat area at S-12.

1.29.5 Noise Assessment at PBR-S12

A comparison of TEM-8 S/N with ORAGS-Arrowhead airborne magnetometer S/N was performed, using data acquired in 2002 by the Battelle team while they were employed at Oak Ridge National Laboratory. Because no anomalies could be recognized in the total field magnetometer data from the PBR-S12 target, the value for signal was established from measurements of a largely intact M38. We used the same M38 as a test item for the TEM-8 test grid at FKPBR and for the VG system at Twentynine Palms in January 2008. The TEM-8 response to this M38 was 67.3 ppm, and the analytic response (taken from the gridded analytic signal data from the Twentynine Palms test grid) was 46.6 nanoteslas per meter (nT/m).

At PBR-S12, a 2.6-acre area was selected for noise assessment (Figure 27), based on the sparseness of TEM-8 anomalies in that area and distance from the target center. As before, the standard deviation of the profile data was calculated within each of the blocks for both data sets to provide a measure of noise. Based on these estimations, the SNR for TEM-8 and ORAGS-Arrowhead systems at S-12 were determined, as summarized in Table 7-7.

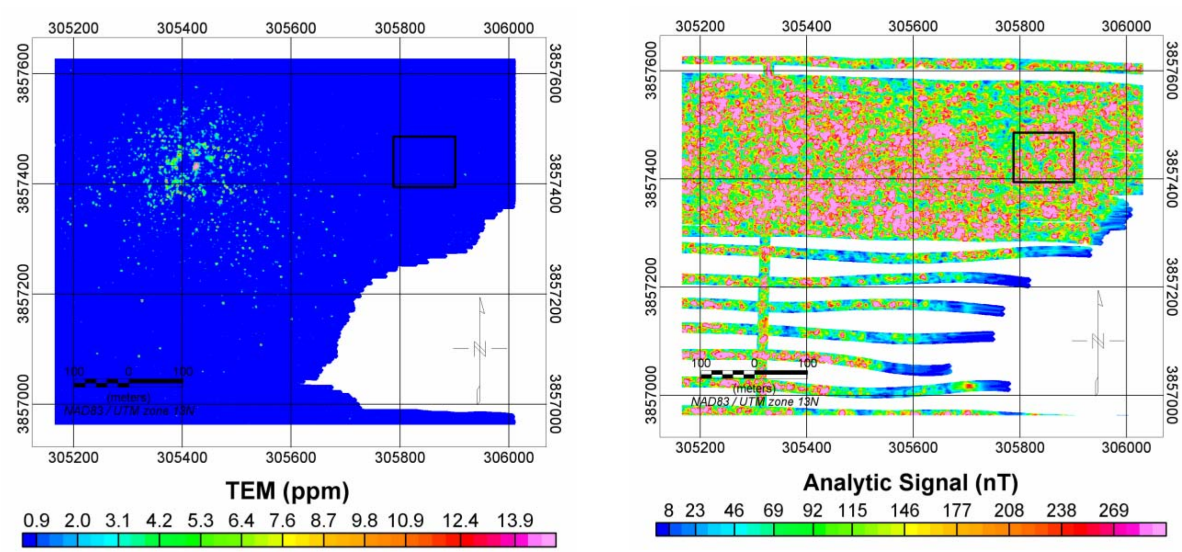

Figure 27. Areas chosen for noise assessment, depicted as boxes on the TEM-8 (left) and ORAGS-Arrowhead Analytic Signal (right) maps.

The TEM-8 SNRs for M38s at PBR-S12 are larger than those reported at FKPBR because of the large response generated by M38s in both magnetic and electromagnetic systems (Table 7-8). The extreme improvement in SNR for TEM-8 over the magnetometer system is due primarily to the very large noise levels that occur with magnetometers over basalts. The important result here is the ratio of TEM-8 SNR to Arrowhead SNR, nearly 1300 times better, which is representative of the improvement that can be expected when using electromagnetic systems rather than magnetometer systems in severe basaltic environments.

Table 7-8. SNR comparison for an M38 at PBR-S12

	TEM-8	ORAGS-Arrowhead
Estimated Noise	0.23 ppm	204.5nT/m
Estimated Signal	67.3 ppm	46.6 nT/m
SNR	292.7	0.23

ppm = parts per million
nT/M = Nanoteslas per meter

1.30 Discussion

By all measures, the performance of the TEM-8 at FKPBR and PBR-S12 exceeded expectations, as indicated by the performance metrics. Nearly all blind-seeded items were detected with amplitudes that were well above the noise floor, suggesting that in hindsight, it would have been better to have emplaced smaller items, such as 60 mm mortars in addition to the ones that were seeded. Test grid results (see Figure 9), which included TEM-8 measurements of 60 mm, support a view that some portion of these would have been detected had they been included. The PBR-S12 results demonstrated the ability of the system to detect a portion of the frag smaller than 1 pound.

In both areas, the system also appears to indicate lower numbers of false positives than typically seen with magnetometer systems. At the FKPBR blind-seeded grid, 109 seeded items were detected within the first 565 prioritized digs, a hit: unknown ratio of about 1:4. In this case, many, if not most of the unknown anomalies are likely associated with ordnance or frag associated with the periphery of the N-3 target or its satellite targets. Figure 13, which shows the TEM-8 map of the 617-acre area at FKPBR shows concentrations of anomalies that appear to be like those of bombing targets, which seem to continue into the 100-acre blind-seeded area. Similarly, approximately 81 percent of the TEM-8 anomalies that were excavated in Grids 1 and 4 at PBR-S12 were shown to be associated with ordnance or frag.

In determining the suitability of an area for TEM-8 operation, one of the most critical factors is the altitude at which the site may be flown. Figure 9 provides a basis for estimating the sensitivity of the system to various types of ordnance as a function of altitude. The results of this study indicate that TEM-8 should be a valuable tool for WAA surveys, particularly in those areas where geologic interference is problematic for magnetometer systems.

COST ASSESSMENT

The cost of an airborne survey depends on many factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site, fuel costs, terrain and vegetation conditions impacting flight line configuration and turn-around, etc.,
- Total size of the blocks to be surveyed,
- Length of flight lines,
- Extent of topographic irregularities or vegetation that can influence flight variations and performance,
- Ordnance objectives which dictate survey altitude and number of flight lines,
- Temperature and season, which control the number of hours that can be flown each day,
- Location of the site, which can influence the cost of logistics,
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction, and
- Swath width and continuity; some systems require interleaving for full coverage, and hence can require more flying than others.

The difference in cost for the TEM-8 electromagnetic and VG-16 vertical magnetic gradient systems lies largely in their swath. The VG-16 system acquires data along an entire 12 m swath with each pass, while the TEM-8 requires twice as many flight passes to cover the same area. This causes the acquisition cost to be nearly double for the TEM-8.

1.31 Cost Model

Cost information associated with the demonstration of the TEM-8 airborne technology was closely tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. It is important to note that the costs for airborne demonstrations and surveys are very much dependent on the character, size, and conditions at each site; ordnance objectives of the survey (e.g. flight altitude); type of survey conducted (e.g. high-density or transects); and technology employed for the survey (e.g. total field magnetic, vertical magnetic gradient, time domain electromagnetic induction) so that a universal formula cannot be fully developed. For this demonstration, Table 8-1 contains the cost elements that were tracked and documented for this demonstration. These costs include both operational and equipment costs associated with system application; mobilization and demobilization of equipment and personnel; salary and travel costs for project staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; and costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

Table 8-1: Cost elements for TEM-8 survey demonstration at FKPBR and PBR-S12.

Cost Category	Sub Category	Details	Quantity	Battelle Cost[1] (in dollars)	AMEC Costs (in dollars)
Pre-Survey (Start-up)	Site Characterization	Site inspection	4 days		$14,859
		Mission Plan preparation & logistics	18 days	$31,434	$33,615
		Calibration Site preparation	2 days	$8,555	$5,822
	Mobilization	Equipment/personnel transport (includes travel):	3 days	$9,641	
		Helicopter/personnel transport (includes travel)	4 days	$24,331	
		Unpacking and system installation:	1 day	$7,073	
		System testing & calibration	1 day	$2,796	
Pre-survey Subtotal				**$83,830**	**$54,296**
Capital Equipment	System Use Rate ($700/day)		25 days	$17,500	
Capital Subtotal				**$17,500**	
Operating Costs	Data acquisition	Helicopter time, including pilot and engineer labor	18 days (74 hours air-time)	$100,664	
	Operator labor		14 days	$8,100	
	Field Data processing	Geophysicist	18 days	$39,442	
	Field support/management	Geophysicist/Manager	18 days	$24,256	$17,544
	Maintenance	Geosoft software maintenance		$0	
	Hotel, air fares, and per diem	Survey team	18 days	$7,267	$4,687

Cost Category (continued)	Sub Category (continued)	Details (continued)	Quantity (continued)	Battelle Cost[1] (in dollars) (continued))	AMEC Costs (in dollars) (continued)
Operating Costs	Fuel Truck	Remote re-fueling[2]	4 days	$800	
	Airport Landing Fees and FBO Fees		18 days	$1,170	
	Project management		4 days	$6,930	$38,032
Operating Cost Subtotal				**$187,829**	**$60,263**
Cost Category	**Sub Category**	**Details**	**Quantity**	**Battelle Cost[1]** (in dollars)	**AMEC Costs** (in dollars)
Post-Survey	Demobilization	Disassembly from helicopter, packing, and loading for transport:	1 day	$6,391	
		Equipment/personnel transport (includes travel):	3 days	$9,821	
		Helicopter/personnel transport (includes travel):	3 days	$18,364	
	Additional data processing, analysis, interpretation, and Reporting (Oak Ridge)			$119,703	
	Geophysical Investigation	Mobilization, validation, demobilization			$106,719
	Reporting (AMEC)				$20,636
Post-Survey Subtotal				**$154,279**	**$127,355**

Total Cost		**$443,438**	**$241,914**
Total Costs Combined		**$685,352**	

[1]Includes all overhead and organization burden, fees, and associated taxes
[2]Remote refueling was required only at the PBR-S12 site.
*Costs reported are through November 2009.

1.32 Cost Drivers

The cost of an airborne survey depends on many factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site, fuel costs, terrain and vegetation conditions impacting flight line configuration and turn-around, etc.,
- Total size of the blocks to be surveyed,
- Length of flight lines,
- Extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives which dictate survey altitude and number of flight lines
- Temperature and season, which control the number of hours that can be flown each day
- Location of the site, which can influence the cost of logistics
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction.

The difference in cost for the VG-16 (magnetometer) and TEM-8 systems lies largely in their swath. The VG-16 system acquires data along an entire 12 m swath with each pass, while the swath of the TEM-8 system consists of two 3 m lobes with an intervening 6 m inactive central zone where helicopter noise level is unacceptable. The TEM-8 therefore produces a 6 m swath compared to the 12 m swath of the VG-16 or the 6 m swath of the VG-22.

The major cost drivers for an airborne survey are the cost of helicopter services and the data processing and analysis associated with the acquired data. In terms of tasks, these constitute the majority of the field-related costs (i.e. mobilization, data acquisition, and demobilization costs) which represent the single largest cost item for an airborne survey project.

As mentioned, helicopter services are a significant component of the costs associated with the airborne survey project. This cost element is included in the mobilization, data acquisition, and demobilization tasks. The costs include helicopter airtime, fuel, pilot, aircraft engineer (mechanic), airport landing/hanger fees (if applicable), and per diem for the flight crew. Depending on survey location (distance from home base), mobilization and demobilization costs can be significant when compared to the overall data acquisition cost. Additionally, the type of survey, weather conditions, length of survey day, terrain, vegetation, and cultural features will greatly influence this cost element.

Data processing and analysis functions constitute the majority of the remaining costs associated with the field-related costs for a survey. As with helicopter services, mobilization and demobilization of the airborne survey equipment and the geophysical survey team is also a major task in terms of cost. This is typically a function of distance from the home base or previous survey location (i.e. if shared mobilization/demobilization is involved) to the intended survey project site. Peripheral costs associated with this demonstration-validation project, such as ground truth and excavations, are not part of the cost analysis in this section and the following section (8.2 and 8.3).

The sensitivity of the overall cost to these drivers can be modeled under several different scenarios. Helicopter time on site is a factor of several variables. The first is the number and dimensions of the survey blocks. The greatest amount of non-survey time is spent in turns at the end of each line in preparation and alignment for the next line. As such, fewer and longer survey lines are more efficient than numerous shorter ones. Typically, lines longer than approximately 3-5 kilometer (km) do not gain additional efficiencies. One mitigating factor to this limit is a pilot performance issue. Longer lines typically require more frequent re-flights, since it is more difficult to maintain precision flying over such long lines. In practice, a maximum line length of 5 km is recommended.

As discussed above, other major cost drivers are mobilization, data processing, and demobilization. These costs are a function of project size and transportation distance, respectively. Processing costs and data delivery times typically decrease with experience at multiple sites.

1.33 Cost Benefit

This section compares costs of three different survey technologies. These include man-portable, the ground-based MTADS system, and the TEM-8 airborne electromagnetic system. Operational costs for the TEM-8 system are equivalent to those of the Battelle VG-22 system because of their similar swath width. The difference in swath width for both systems results in higher cost than for the VG-16 vertical magnetic gradient system, which has a 12 m swath width. However, as noted throughout this report, the TEM-8 system was designed for use in areas where magnetometer systems are inappropriate.

Based on several sources of information regarding the deployment of ground-based towed array systems on a UXO contaminated site, five scenarios are presented for the purpose of comparing airborne surveys to ground-based surveys. These sources of information are generally informal and include discussions both with industry and U.S. Army Engineering and Support Center, Huntsville (USAESCH) staff experienced in the application of ground-based towed array surveying equipment and projects.

Following Harbaugh et al., 2007, we assume that the two ground-based technologies might survey only 2 percent of the total area of concern, while the airborne systems would survey between 2 percent and 100 percent. This level of ground surveying has been used in ESTCP's Wide Area Assessment Pilot Program. We also include higher proportions of ground surveying for comparison purposes. Harbaugh et al. have proposed fixed costs of $75k (mobilization, demobilization, reporting) and acreage costs of $500/acre for use of MTADS at two sites. We assume that costs for a towed EM61 array would be roughly equivalent to those for the MTADS towed array. Similarly, Harbaugh et al. submit fixed costs of $45k plus acreage rates of $1540/acre for man portable electromagnetic surveys at these sites.

Comparisons between airborne, vehicle, and man-portable magnetometer surveys are summarized in Table 8-2. These scenarios address sites of 1,000 to 50,000 acres of geographic extent, with varying rates of coverage from 100 percent to 2 percent. TEM-8 airborne costs range from $136 to $291 per acre for a 100 percent coverage survey using the TEM-8 WAA

system. These costs include a nominal $50,000 mobilization cost from our bases of operation in Tennessee and Ontario, Canada. Airborne costs are corroborated by recent work with magnetometer systems for non-ESTCP sponsors, e.g. the surveys at Kirtland Air Force Base (AFB), Fort McCoy, Camp Lejeune, Pinecastle Range Complex, and Fort Ord.

Man-portable systems generally have significantly higher acquisition costs than airborne systems (ranging from $500 to $3,000 per acre, depending on site conditions), are extremely time-consuming, and may present risks to personnel, equipment, and the environment. Neither the airborne nor the ground based survey costs include the cost of excavation

Comparison of the airborne array to a ground-based towed array similar to MTADS may be more representative for several reasons:

- MTADS was deployed at several of the same sites as the airborne technology (as reflected in several IDA reports), which enables an easy comparison for broad-area search technology.
- USAESCH performed an assessment of costs associated with contractors that employ ground-based towed arrays for geophysical surveying at UXO sites.

The extent of coverage possible with an airborne system renders comparisons to hand-held man-portable systems somewhat inappropriate. Although somewhat simplistic and generalized in nature, it is readily apparent that the advantage of airborne surveys over ground-based surveys becomes greater as the area of concern becomes larger. These figures illustrate that for EM surveys, man-portable platforms are most cost effective for sites requiring less than 30 acres of actual coverage. Vehicular systems are most effective for 30-400 acres, and airborne systems are most effective for sites larger than 400 acres.

Table 8-2: Costs for airborne, ground vehicle and man-portable survey platforms for varying WAA survey densities. Shaded cells are minimum cost. Man-portable are most cost effective for 0-30 acres actual coverage, vehicular systems from 30-400 acres and airborne over 400 acres. All costs are in thousands of dollars and include fixed mobilization costs.

Table 8-2 TEM-8

Acres	100%	50%	25%	10%	2%
1,000	$ 291	$ 234	$ 189	$ 184	$ 180
2,000	$ 433	$ 319	$ 242	$ 219	$ 214
5,000	$ 833	$ 518	$ 380	$ 286	$ 257
20,000	$ 2,786	$ 1,456	$ 852	$ 541	$ 365
50,000	$ 6,835	$ 3,399	$ 1,893	$ 995	$ 511

All costs are in thousands of dollars and include fixed mobilization costs.

Table 8-2 Vehicle

Acres	100%	50%	25%	10%	2%
1,000	$ 575	$ 325	$ 200	$ 125	$ 85
2,000	$ 1,075	$ 575	$ 325	$ 175	$ 95
5,000	$ 2,575	$ 1,325	$ 700	$ 325	$ 125
20,000	$ 10,075	$ 5,075	$ 2,575	$ 1,075	$ 275
50,000	$ 25,075	$ 12,575	$ 6,325	$ 2,575	$ 575

All costs are in thousands of dollars and include fixed mobilization costs.

Table 8-2: Costs for airborne, ground vehicle and man-portable survey platforms for varying WAA survey densities *continued*.

Table 8-2 Man

Acres	100%	50%	25%	10%	2%
1,000	$ 1,585	$ 815	$ 430	$ 199	$ 76
2,000	$ 3,125	$ 1,585	$ 815	$ 353	$ 107
5,000	$ 7,745	$ 3,895	$ 1,970	$ 815	$ 199
20,000	$ 30,845	$ 15,445	$ 7,745	$ 3,125	$ 661
50,000	$ 77,045	$ 38,545	$ 19,295	$ 7,745	$ 1,585

All costs are in thousands of dollars and include fixed mobilization costs.

Table 8-2 Number of Covered Acres

Acres	100%	50%	25%	10%	2%
1,000	1,000	500	250	100	20
2,000	2,000	1,000	500	200	40
5,000	5,000	2,500	1,250	500	100
20,000	20,000	10,000	5,000	2,000	400
50,000	50,000	25,000	12,500	5,000	1,000

Costs for MTADS surveys may vary from those estimated in Table 8-2. The following was extracted from a relevant IDA report (Andrews et al., 2001):

> "For this demonstration, the MTADS total cost was $377,296. If the excavation costs of $169,096 and the reporting costs of $24,000 are removed, the MTADS costs for the deployment, survey, and analysis parts of this demonstration were $184,200. Note that this does not separate out the costs of the EMI work. The MTADS surveyed a total of more than 150 acres for a cost of $1,222 per acre" (Andrews et al., 2001).

For the ORAGS-Arrowhead (which compare favorably with the costs for the VG-16 vertical magnetic gradient system), the total costs for the demonstrations and surveys ranged from $159,096 to $348,080k, for a cost of $86 to $704 per acre, including mobilization. According to the IDA report conclusions, "cost estimates prepared by the performers indicate that the per-acre-cost of the MTADS is about 2–3 times higher than those of airborne systems. These figures are very rough estimates and may not accurately reflect the cost differences seen in operational surveys." The MTADS costs are summarized in Table 8-3. As noted earlier, the VG-22 and TEM-8 airborne surveys have higher cost than the VG-16 surveys due to their narrower swath width.

In Table 8-2, we provided costs for airborne surveys covering between 2 percent and 100 percent of the area of interest with ground-based surveys covering 2 percent of the area of interest. An unresolved question is where the equivalency would lie between airborne and ground-based technologies: Which is more valuable, a 10 percent airborne survey, or a 2 percent ground-based survey? The answer would clearly lie in the delectability of the ordnance of interest at the site for both systems, and the uncertainty about ordnance contamination in areas that are not surveyed. The greater sensitivity of ground-based systems must be balanced against the probability of ordnance contamination within areas that are not surveyed. The choice will likely

vary from site-to-site. Ground-based systems have more cost constraints that are site-dependent than airborne systems (e.g. unnavigable terrain, vegetation that must be cleared, vibration-sensitive ordnance, etc.), and this may also affect the selection of approaches.

Table 8-3: Representative cost for MTADS ground-based survey

Cost Category	Sub Category	Costs ($)
Fixed Costs		
1. Capital Costs	**Mobilization/Demobilization**	6,614
	Planning/Preparation/Health and Safety Plan (Mission Plan)	1,746
	Equipment	Included in Survey Cost
	Management Support	Included in Survey Cost
		Subtotal 8,360
Variable Costs		
2. Operation And Maintenance	**Ground-Based Survey**	129,650
	Labor for Data Processing, Analysis, and Interpretation	37,800
	Instrument Rental or Lease	Included in Survey Cost
	Travel and Miscellaneous Materials	26,060
	Reporting	4,230
		Subtotal 197,740
3. Other Technology-Specific Costs	**Excavation for Ground-Truthing and Verification**	Not Included
	Geophysical Prove-out	5,616
		Subtotal 5,616
4. Miscellaneous Costs	**None Noted**	0
Total Costs		
		Total Technology Cost 211,716
		Throughput Achievable (acres per hour) 3
		Unit Cost per acre 735

1.34 Cost Conclusions

As demonstrated above, comparing costs of fundamentally different technology approaches is both difficult and inconclusive. The previously discussed cost comparison provided a range of answers to the same question, namely, what are the costs of deploying each technology over the same size area under the same conditions?

For consideration of DoD-wide application of the airborne technology, a number of factors must be considered when evaluating the appropriateness of the airborne technology and potential for substantial cost savings. While initially impressive, it is not possible to simply apply these types of cost savings across the entire DoD UXO program. Sites must be of sufficient geographic extent to warrant a deployment given the high costs associated with mobilization and demobilization. In addition, survey objectives, terrain, geology, vegetation, and cultural artifacts must also be considered for such a deployment. Extremely variable terrain and/or the presence of tall vegetation can greatly limit or impede the use of the airborne technology for the UXO

objectives of interest. Finally, the project objective must be consistent with the detection limits and capabilities of the airborne system to make such a deployment feasible.

IMPLEMENTATION ISSUES

Regulatory Issues

In order to operate, each system must have Federal Aviation Administration approval (Supplemental Type Certificate (STC) certificate). The required testing and evaluation was completed before mobilization. In addition, ground crews are required to complete the 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) course and to maintain their annual 8-hour refreshers for operation at most UXO sites. We are aware of no additional regulatory requirements for operation at the FKPBR site.

End-User Issues

The primary stakeholders for UXO issues at the FKPBR site have not been specified.

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POINTS OF CONTACT

Table 11-1: Points of Contact

Point Of Contact	Organization Name and Address	Phone/Fax/Email	Role in Project
Raye Lahti	AMEC E&E 800 Marquette Ave Suite 1200 Minneapolis MN 55402	715-794-2889 651-767-2335 raye.lahti@amec.com	Project Manager
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Appendix A: Data Storage and Archiving Procedures

Data Format

All data are recorded by automated collection systems. All raw data are write-protected and all intermediate data are retained in the root database. Selection and ranking of anomalies for investigation are made by a combination of automated routines and manual refinement.

All data are handled in SI units, and all positioning data are compiled in the NAD83 UTM projection. Alternate units and/or projections may be accommodated after the final data processing.

Data files included:
The archive files that are provided to ESTCP as a supplement to the Final Report are listed in Table B-1.

Table A-1. Archive files provided to ESTCP

	Dig Lists	XYZ grids	GeoTiffs	Data
FKPBR	Kirt_seeded_picks	FKPBR.dat	FKPBR.tif	FKPBR.asc
	Kirt_seeded_picks_rankA	FKPBR-Alt.dat	FKPBR-Alt.tif	
	Kirt_seeded_picks_rankB			
	Kirt_seeded_picks_rankC			

	Dig Lists	XYZ grids	GeoTiffs	Data
S12	S12_grid1_picks.XYZ	S12.dat	S12.tif	S12.asc
	S12_grid2_picks.XYZ	S12-Alt.dat	S12-Alt.tif	
	S12_grid3_picks.XYZ	S12_grid1.dat		
	S12_grid4_picks.XYZ	S12_grid4.dat		
	S12_grid5_picks.XYZ			

Dig lists: Lists of anomalies that might represent UXO related targets
XYZ grid files: Grid files for all data represented in map form
GeoTiff Image files
Final Databases: All data that has been used to generate grids and maps above

Pick lists have the following format:

Target_ID	x (utm-m)	y (utm-m)	TEM
1937	336641.0	3892937.0	137.030
1902	336216.0	3892930.0	82.849
1717	336660.0	3892900.0	45.252
6462	336589.0	3893562.0	19.019

Target ID: ID given to each target
x (utm-m): Universal Transverse Mercator x coordinate in meters
y (utm-m): Universal Transverse Mercator y coordinate in meters
TEM: TEM response of anomaly

XYZ grid Files Format:

x (utm-m)	y (utm-m)	Value
336641.0	3892937.0	137.030

x (utm-m): Universal Transverse Mercator x coordinate in meters
y (utm-m): Universal Transverse Mercator y coordinate in meters
Value: The value of the parameter that has been gridded (i.e. TEM response, Altitude)

Tiff Image files:
Georeferenced image files of all gridded data.

Database Format:

X	Y	hae	Alt	TEM	Line

x: Universal Transverse Mercator x coordinate in meters
y: Universal Transverse Mercator y coordinate in meters
hae: Height above ellipsoid in meters
Alt: Sensor height above ground in meters
TEM: TEM response amplitude
Line: Line #

Appendix B: Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1001	1859	MD	1	4	8	30	180	0	5/19/2009	M38 body
1002	2880	MD	1	0	12	30	0	0	5/16/2009	M38 crumpled
1003	2625	MD	1	0	8	20	0	0	5/18/2009	M38 crumpled
1004	1150	MD	1	2	10	1.5	0	0	5/12/2009	Nose cone
1005	1600	MD	1	7	19	100	170	0	5/14/2009	M38, 24" long and full
1006	1964	MD	1	0	0	0.5	0	0	5/13/2009	10" x 12" piece
1007	1407	MD	1	6	16	8	0	0	5/13/2009	M38 crumpled
1008	1605	MD	1	0	12	5	0	0	5/14/2009	M38 crumpled
1009	590	MD	1	0	2	0.1	0	0	5/16/2009	2" band
1010	919	MD	1	6	18	5	0	0	5/13/2009	M38 crumpled
1011	1040	MD	8	0	10	1.5	0	0	5/12/2009	2" band, 8 pieces
1012	2032	MD	1	0	6	30	0	0	5/18/2009	M38 crumpled
1013	940	MD	1	1	4	1	0	0	5/18/2009	Nose cone
1014	696	MD	1	6	10	15	0	0	5/19/2009	M38 tail
1015	890	MD	2	6	10	1	0	0	5/16/2009	2" band and nose cone
1016	1480	MD	1	4	12	20	0	0	5/16/2009	M38 crumpled
1017	1715	MD	1	6	12	5	0	0	5/18/2009	M38 crumpled
1018	620	MD	1	4	10	1	0	0	5/14/2009	Nose cone
1019	114	MD	1	10	36	85	45	0	5/18/2009	M38 body in cactus
1020	1129	MD	3	0	0	0.1	0	0	5/12/2009	Tail, spotting charge and receiver
1021	750	MD	1	4	10	1	0	0	5/16/2009	Nose cone
1022	905	MD	1	6	16	5	0	0	5/13/2009	M38 crumpled
1023	355	MD	1	0	4	1	0	0	5/18/2009	Nose cone
1025	627	MD	1	8	18	20	180	0	5/16/2009	M38, vertical
1026	904	MD	1	2	8	3	0	0	5/14/2009	M38 crumpled
1027	560	MD	1	6	10	1	0	0	5/14/2009	M38 tail assembly
1028	738	MD	1	4	16	10	0	0	5/16/2009	M38 crumpled
1029	962	MD	3	6	6	35	0	0	5/11/2009	M38 base & pieces
1030	518	MD	1	2	6	1	0	0	5/18/2009	Nose cone
1031	966	MD	1	2	6	1	0	0	5/14/2009	Nose cone
1032	625	MD	9	0	12	3	0	0	5/13/2009	Initiator and 8 pieces
1033	474	MD	1	6	10	1	0	0	5/18/2009	Nose cone
1034	740	MD	1	4	6	1.5	0	0	5/12/2009	Nose cone

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1035	680	MD	1	4	8	1	0	0	5/16/2009	Nose cone
1036	545	MD	1	0	0	0.1	0	0	5/14/2009	5" x 7" piece
1037	622	MD	2	4	10	15	0	0	5/18/2009	2" band and body
1038	560	MD	1	6	10	4	0	0	5/13/2009	M38 body
1039	320	MD	2	12	16	1	0	0	5/18/2009	Nose cone and band
1040	604	MD	1	6	12	3	0	0	5/16/2009	Same as 1255
1041	408	MD	1	6	10	20	0	0	5/16/2009	M38 crumpled
1042	487	MD	2	4	8	2	0	0	5/11/2009	M38 nose cone
1043	493	MD	1	4	8	1	0	0	5/14/2009	Nose cone
1044	465	MD	2	10	14	1	0	0	5/18/2009	2" band and nose cone
1045	929	MD	2	2	12	2	0	0	5/12/2009	M38 in pieces
1046	975	MD	1	6	10	5	0	0	5/13/2009	M38 crumpled
1047	640	MD	1	0	10	0.25	0	0	5/12/2009	6" x 12" M38
1048	295	MD	1	6	10	1	0	0	5/18/2009	Nose cone
1049	360	MD	2	0	24	1	0	0	5/14/2009	2" band and nose cone at 20"
1050	219	MD	1	6	10	3	0	0	5/11/2009	Nose
1051	318	MD	2	2	10	0.5	0	0	5/12/2009	Band and nose cone
1052	365	MD	1	6	10	1	0	0	5/16/2009	Nose cone
1053	484	MD	1	0	0	1	0	0	5/18/2009	Fin, 5" x 7"
1054	320	MD	1	8	12	1	0	0	5/18/2009	Nose cone
1055	275	MD	1	2	10	1.5	0	0	5/12/2009	Nose cone
1056	104	MD	2	0	0	0.1	0	0	5/12/2009	Spotting charge receiver
1057	280	MD	1	14	20	0.5	0	0	5/13/2009	Nose cone
1058	310	MD	1	1	1	0.1	0	0	5/11/2009	2" band
1059	254	MD	1	2	3	0.1	0	0	5/18/2009	6" x 8" piece
1060	243	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1061	141	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1062	242	MD	1	12	20	8	45	0	5/18/2009	M38 crumpled - same as 1236
1063	1285	MD	1	0	12	60	0	0	5/18/2009	M38 crumpled - same as 1228
1064	205	MD	1	0	0	0.1	0	0	5/18/2009	2" strap
1065	164	MD	1	0	0	0.5	0	0	5/12/2009	Initiator
1066	202	MD	1	1	1	0.1	0	0	5/18/2009	2" band
1067	246	MD	2	12	10	0.5	0	0	5/12/2009	2" band and Initiator

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1068	174	MD	1	1	1	0.1	0	0	5/13/2009	2" band
1069	80	MD	1	2	2	0.5	0	0	5/11/2009	M1A1 Initiator
1070	400	MD	2	3	4	0.5	0	0	5/12/2009	Nose and band
1071	257	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1072	360	MD	3	8	16	3	0	0	5/11/2009	M38 - 12" x 12" pieces
1073	167	MD	1	12	16	1.5	0	0	5/12/2009	Nose cone
1074	432	MD	1	0	0	0.25	0	0	5/12/2009	6" x 12" piece
1075	410	MD	1	2	4	1	0	0	5/18/2009	Nose cone
1076	186	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1077	178	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1078	98	MD	1	0	0	0.1	0	0	5/14/2009	2" band and lug
1079	128	MD	1	0	0	0.1	0	0	5/13/2009	2" band & lug
1080	294	MD	2	4	8	0.25	0	0	5/14/2009	2 pieces, 8" x 8"
1081	161	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1082	154	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1083	143	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1084	97	MD	1	1	1	0.1	0	0	5/19/2009	2" band
1085	50	MD	1	0	0	0.2	0	0	5/19/2009	2" x 2" band
1086	157	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1087	163	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1088	164	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1089	143	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1090	115	MD	1	0	0	0.1	0	0	5/16/2009	2" band and cap. Near 1117
1091	143	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
1092	143	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1093	225	MD	2	0	0	0.5	0	0	5/12/2009	Initiator & band
1094	212	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
1095	120	MD	1	0	0	0.1	0	0	5/13/2009	2" band
1096	168	MD	1	0	0	0.5	0	0	5/12/2009	M1A1 Initiator
1097	121	MD	1	0	0	0.5	0	0	5/16/2009	Initiator
1098	136	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
1099	120	MD	1	0	0	0.5	0	0	5/12/2009	Initiator
1100	286	MD	1	3	5	0.1	0	0	5/18/2009	5" x 7" piece

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1101	278	MD	2	4	12	1	0	0	5/12/2009	M38 12" x 15" piece and band
1102	516	MD	1	0	0	0.25	0	0	5/12/2009	12" x 12" and cactus
1103	175	MD	2	2	10	0.5	0	0	5/12/2009	2" band and nose (close to cactus)
1104	188	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1105	98	MD	1	0	0	0.1	0	0	5/16/2009	2" band
1106	1630	MD	1	4	10	20	0	0	5/18/2009	M38 body
1108	117	MD	1	0	0	0.1	0	0	5/13/2009	2" band
1109	135	MD	1	0	0	1.5	0	0	5/12/2009	Initiator
1110	194	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1111	119	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1112	126	MD	1	2	2	0.1	0	0	5/12/2009	2" band
1114	104	MD	1	1	1	0.1	0	0	5/18/2009	2" band
1115	250	MD	2	2	16	1	0	0	5/14/2009	2" strap and nose cone
1116	188	MD	1	1	1	0.1	0	0	5/19/2009	2" band
1117	160	MD	2	0	0	0.1	0	0	5/14/2009	2" band and cap. Near 1090
1118	223	MD	1	0	0	0.1	0	0	5/18/2009	2" band
1119	101	MD	2	0	4	0.1	0	0	5/12/2009	2" band and ignitor cap
1120	180	MD	1	0	0	0.1	0	0	5/12/2009	3" x 5" piece
1121	121	MD	1	0	0	0.5	0	0	5/18/2009	Initiator
1122	146	MD	1	4	6	0.5	0	0	5/13/2009	4" x 6" piece
1123	87	MD	1	0	0	0.1	0	0	5/18/2009	2" band with lug
1124	125	MD	1	1	1	0.1	0	0	5/19/2009	2" band
1125	205	MD	2	0	0	0.6	0	0	5/18/2009	Initiator and 2" band
1127	124	MD	1	0	0	0.1	0	0	5/13/2009	2" band
1131	105	MD	1	0	10	0.5	0	0	5/13/2009	Initiator
1134	104	MD	1	0	0	0.25	0	0	5/12/2009	2" band
1138	81	MD	1	0	0	0.1	0	0	5/16/2009	Initiator
1142	115	MD	1	4	4	0.5	0	0	5/18/2009	Initiator
1143	101	MD	1	0	0	0.5	0	0	5/14/2009	Initiator receiver
1147	330	MD	1	4	8	0.5	0	0	5/13/2009	Nose cone
1150	103	MD	1	0	0	0.1	0	0	5/18/2009	4" x 5" piece
1168	80	MD	1	2	8	0.5	0	0	5/12/2009	Nose Cone
1169	226	MD	3	6	12	2	0	0	5/13/2009	M38 body & pieces

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1170	77	MD	2	0	4	1	0	0	5/18/2009	Initiator and 5" x 7"
1173	160	MD	3	0	12	1.5	0	0	5/12/2009	Nose cone and pieces
1175	470	MD	1	0	10	10	0	0	5/18/2009	M38 crumpled (under cacti)
1180	80	MD	2	2	6	0.2	0	0	5/12/2009	12" away from 1249, two pieces 4" x 6"
1182	143	MD	1	0	0	0.1	0	0	5/16/2009	2" band
1183	178	MD	1	2	4	0.5	0	0	5/18/2009	Initiator
1187	46	MD	1	2	4	0.1	0	0	5/12/2009	2" x 5" piece
1193	98	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
1201	35	MD	1	0	0	0.1	0	0	5/18/2009	Can cap
1204	32	MD	1	0	0	0.1	0	0	5/13/2009	2" x 4" piece
1207	47	MD	1	0	0	0.5	0	0	5/12/2009	M1A1 Initiator, 1 meter from 1051
1217	36	MD	1	0	0	0.1	0	0	5/12/2009	3" x 3" piece
1218	264	MD	1	6	10	1	0	0	5/16/2009	Nose cone
1223	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
1224	0	NF	0	0	0	0	0	0	5/16/2009	NO FIND
1225	604	MD	1	6	12	3	0	0	5/16/2009	M38 crumpled
1226	28	MD	1	0	0	0.1	0	0	5/16/2009	Can cap
1227	0	NF	0	0	0	0	0	0	5/16/2009	NO FIND
1228	1285	MD	1	0	12	60	0	0	5/18/2009	M38 crumpled - same as 1063
1229	0	NF	0	0	0	0	0	0	5/16/2009	NO FIND
1230	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
1231	505	MD	1	6	10	1	0	0	5/18/2009	Nose cone
1232	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
1233	175	MD	1	6	10	0.2	0	0	5/13/2009	14" x 8" piece
1234	130	MD	3	4	12	1	0	0	5/14/2009	Nose cone pieces
1236	242	MD	1	12	20	8	45	0	5/18/2009	M38 crumpled - same as 1062
1237	0	NF	0	0	0	0	0	0		NO FIND
1240	0	NF	0	0	0	0	0	0	5/14/2009	NO FIND
1242	0	NF	0	0	0	0	0	0	5/14/2009	NO FIND
1243	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
1246	0	NF	0	0	0	0	0	0	5/12/2009	NO FIND
1247	116	MD	1	0	0	0.1	0	0	5/16/2009	2" band
1249	105	MD	1	4	12	0.5	0	0	5/12/2009	12" x1 2" M38, close to 1180

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
1253	0	NF	0	0	0	0	0	0	5/14/2009	NO FIND
1254	0	NF	0	0	0	0	0	0	5/12/2009	NO FIND
1257	NA	MD	1	4	6	0.1	0	0	5/12/2009	4" x 8" piece
1258	49	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
1275	0	NF	0	0	0	0	0	0	5/16/2009	NO FIND
2001	3530	MD	1	0	10	50	0	0	5/15/2009	M38 crumpled
2002	3825	MD	1	0	8	100	90	0	5/14/2009	M38 complete horizontal
2003	2375	MD	1	2	10	30	0	0	5/15/2009	M38 crumpled
2004	2880	MD	1	0	8	20	0	0	5/15/2009	M38 crumpled
2005	3973	MD	1	0	4	5	0	0	5/12/2009	M38 crumpled
2006	2205	MD	2	0	6	1	0	0	5/20/2009	Nose cone and 2" strap
2007	2125	MD	1	0	10	30	0	0	5/15/2009	M38 crumpled
2008	3390	MD	1	2	12	8	90	0	5/12/2009	M38 crumpled
2009	1540	MD	1	4	10	4	0	0	5/14/2009	M38 Crumpled
2010	1410	MD	1	4	10	4	0	0	5/14/2009	M38 crumpled
2011	3550	MD	1	1	5	70	0	0	5/15/2009	M38 complete
2012	1730	MD	1	0	12	3	0	0	5/15/2009	M38 crumpled
2013	1827	MD	1	4	20	15	0	0	5/14/2009	M38
2014	1740	MD	1	0	0	0.1	0	0	5/13/2009	14" x 6" piece
2015	360	MD	1	4	10	1	0	0	5/19/2009	Nose cone
2016	1005	MD	1	4	10	4	0	0	5/14/2009	M38 crumpled
2017	1080	MD	1	6	14	20	0	0	5/15/2009	M38 crumpled
2018	1552	MD	1	2	10	10	0	0	5/15/2009	M38 crumpled
2019	963	MD	1	2	12	30	0	0	5/15/2009	M38 crumpled
2020	1236	MD	1	8	12	4	0	0	5/13/2009	M38 crumpled
2021	1450	MD	1	0	16	5	0	0	5/12/2009	M38 body
2022	1350	MD	1	0	0	0.1	0	0	5/15/2009	Tail and receiver
2023	258	MD	4	0	12	4	0	0	5/12/2009	M38, 4 pieces, crumpled
2024	820	MD	2	2	6	2	0	0	5/14/2009	Nose cone and piece
2025	709	MD	1	0	0	0.1	0	0	5/14/2009	5" x 7" piece
2026	880	MD	2	6	10	1	0	0	5/12/2009	Nose cone and 2" band
2027	920	MD	1	2	6	1	0	0	5/15/2009	Nose cone
2028	1010	MD	1	0	8	15	0	0	5/15/2009	M38 crumpled

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
2029	1440	MD	1	4	10	0.5	0	0	5/12/2009	Nose cone
2030	580	MD	2	8	12	1	0	0	5/15/2009	2" band and nose cone
2031	910	MD	1	2	10	4	0	0	5/13/2009	M38 crumpled
2032	478	MD	1	10	14	5	0	0	5/12/2009	Nose cone
2033	540	MD	1	6	10	1	0	0	5/16/2009	Nose cone
2034	32	MD	1	0	0	0.1	0	0	5/13/2009	8" x 4" piece
2035	550	MD	1	12	16	1	0	0	5/15/2009	Nose cone
2036	536	MD	1	4	8	20	0	0	5/15/2009	M38 crumpled
2037	666	MD	1	4	8	4	0	0	5/12/2009	12" x 12" piece
2038	465	MD	1	8	12	1	0	0	5/13/2009	Nose cone
2039	1035	MD	1	8	20	5	0	0	5/15/2009	M38 crumpled
2040	535	MD	1	0	0	0.2	0	0	5/14/2009	5" x 7" piece
2041	292	MD	1	0	0	0.1	0	0	5/12/2009	6" x 6" piece
2042	1148	NMD	1	0	0	0.1	0	0	5/15/2009	1 gallon can
2043	857	MD	1	8	14	13	0	0	5/15/2009	M38 crumpled
2044	655	MD	1	0	0	0.1	0	0	5/15/2009	2" strap
2045	1750	MD	1	0	0	2	0	0	5/14/2009	12" x 8" piece
2046	598	MD	1	0	0	0.1	0	0	5/14/2009	5" x 7" piece
2047	470	MD	1	0	0	0.1	0	0	5/12/2009	5" x 7" piece
2048	566	MD	1	0	0	0.1	0	0	5/14/2009	5" x 7" piece
2049	210	MD	2	14	18	1	0	0	5/14/2009	Nose cone and band
2050	545	MD	1	12	22	70	180	0	5/15/2009	M38 complete
2051	566	MD	1	1	2	0.2	0	0	5/14/2009	5" x 10" nose cone piece
2052	535	MD	1	0	0	0.1	0	0	5/14/2009	5" x 7" piece
2053	556	MD	1	0	0	0.1	0	0	5/12/2009	5" x 8" piece
2054	340	MD	1	0	0	0.1	0	0	5/13/2009	5" x 7" piece
2055	450	MD	1	10	28	30	180	0	5/15/2009	M38 complete. Same 2183
2056	375	MD	2	2	10	0.5	0	0	5/12/2009	2" strap and nose cone
2057	362	MD	1	6	10	3	0	0	5/14/2009	M38 crumpled
2058	437	MD	1	8	14	13	0	0	5/15/2009	M38 crumpled
2059	345	MD	1	4	10	5	0	0	5/15/2009	M38 crumpled
2060	565	MD	1	2	6	2	0	0	5/15/2009	7" x 8" piece
2061	246	MD	1	0	0	0.1	0	0	5/12/2009	6" x 6" flat

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
2062	1052	MD	1	0	0	1	0	0	5/15/2009	Carrying band - unknown
2063	146	MD	2	0	0	0.1	0	0	5/15/2009	2" pieces
2064	34	MD	1	6	10	1	0	0	5/13/2009	Nose cone
2065	186	NMD	1	0	0	0.1	0	0	5/12/2009	NMD - fence tie
2066	136	MD	1	0	0	0.1	0	0	5/14/2009	2" band
2067	331	MD	1	8	12	1	0	0	5/16/2009	Nose cone
2068	21	MD	1	0	0	0.1	0	0	5/14/2009	2" x 2" piece
2069	242	MD	1	4	8	1	0	0	5/14/2009	Nose cone
2070	465	MD	2	1	4	15	0	0	5/15/2009	Tail and section of body
2071	563	MD	1	4	8	1	0	0	5/14/2009	Nose cone
2072	390	MD	1	0	0	0.1	0	0	5/12/2009	5" x 8" piece
2073	335	MD	1	0	0	0.1	0	0	5/14/2009	5" x 9"
2074	195	MD	1	15	21	0.5	180	0	5/12/2009	Nose cone
2075	125	MD	1	6	10	1	0	0	5/14/2009	Nose cone
2076	197	MD	1	12	18	2	0	0	5/13/2009	M38 crumpled
2077	210	MD	1	12	18	1	0	0	5/12/2009	Nose cone
2078	202	MD	1	8	14	1	0	0	5/15/2009	Nose cone
2079	224	MD	1	0	0	0.5	0	0	5/15/2009	Initiator
2080	152	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
2081	255	MD	1	8	16	1	0	0	5/13/2009	Nose cone - same as 2182
2082	136	MD	1	0	0	0.5	0	0	5/15/2009	Initiator
2083	195	MD	1	1	2	0.1	0	0	5/15/2009	Initiator cap
2084	210	MD	2	0	12	1	0	0	5/13/2009	Surface pieces and nose cone
2085	224	MD	2	4	15	2	0	0	5/15/2009	Initiator cap and M38 crumpled
2086	165	MD	1	1	6	0.1	0	0	5/12/2009	2" strap
2087	78	MD	6	16	24	0.5	0	0	5/12/2009	M38, 6 pieces
2088	296	MD	6	1	2	0.1	0	0	5/14/2009	6 pieces spread over 2 feet
2089	87	Non-MD	1	0	0	0.1	0	0	5/13/2009	Wire
2090	179	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
2091	47	MD	4	0	10	1	0	0	5/19/2009	2 lugs, 1 band, 1 nose 14" deep
2092	292	MD	1	2	6	1	0	0	5/13/2009	Nose cone
2093	70	Non-MD	1	0	0	0.1	0	0	5/14/2009	Wire
2094	55	Non-MD	1	0	0	0.1	0	0	5/13/2009	Wire

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
2095	134	MD	1	10	14	1	0	0	5/16/2009	Nose cone
2096	145	NMD	3	0	12	0.1	0	0	5/12/2009	Nails in center of air target
2097	178	MD	1	12	18	0.5	0	0	5/12/2009	Nose cone
2098	123	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
2100	92	NMD	3	0	0	0.1	0	0	5/12/2009	Nails in target
2101	123	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
2102	153	MD	1	0	0	0.5	0	0	5/15/2009	Initiator
2103	146	MD	1	0	0	0.5	0	0	5/13/2009	Initiator
2104	227	Non-MD	1	0	0	0.1	0	0	5/14/2009	Wire
2105	137	MD	1	18	20	1	0	0	5/15/2009	Nose cone
2108	113	MD	1	0	0	0.1	0	0	5/16/2009	Initiator cap
2111	114	MD	1	10	14	1	0	0	5/16/2009	Nose cone
2113	107	MD	1	0	0	0.5	0	0	5/15/2009	Initiator
2114	181	MD	1	0	0	0.5	0	0	5/14/2009	Initiator
2115	98	MD	1	1	2	0.5	0	0	5/12/2009	Initiator
2116	69	Non-MD	1	0	0	0.1	0	0	5/13/2009	Wire
2118	135	MD	2	2	12	1.5	0	0	5/15/2009	Nose cone and piece
2121	115	MD	1	0	0	0.1	0	0	5/15/2009	2" band
2122	143	MD	2	0	10	1.5	0	0	5/12/2009	M38 Pieces
2123	100	MD	1	0	0	0.1	0	0	5/13/2009	Initiator receiver
2125	92	MD	1	4	8	1	0	0	5/13/2009	Nose cone
2127	104	MD	1	1	2	0.1	0	0	5/15/2009	2" band
2128	54	MD	3	0	0	0.1	0	0	5/15/2009	Spotting charge, can and cap
2134	158	MD	1	0	0	0.5	0	0	5/15/2009	Initiator
2136	47	Non-MD	1	0	0	0.1	0	0	5/14/2009	NMD pot handle
2137	119	MD	1	0	0	0.1	0	0	5/14/2009	Initiator cap
2140	122	MD	1	0	0	0.1	0	0	5/14/2009	Initiator cap
2141	64	MD	1	14	21	20	0	0	5/15/2009	M38 mangled
2142	154	MD	1	12	16	1	0	0	5/15/2009	Nose cone
2148	84	MD	1	2	4	0.1	0	0	5/13/2009	2" band
2150	68	MD	1	1	1	0.1	0	0	5/14/2009	2" band
2152	112	MD	1	0	0	0.5	0	0	5/15/2009	Initiator cap
2156	103	Non-MD	1	0	0	0.1	0	0	5/14/2009	Wire

Excavation Data

Target ID	EM61 mV	Target Type	Number of contacts	Depth to Target top (in)	Depth to Target center (in)	Approx. mass (lbs)	Orientation of nose (deg)	Inclination	Date	Comments
2158	80	MD	3	6	10	1	0	0	5/13/2009	3 pieces 4" x 6"
2163	47	NMD	1	0	0	0.1	0	0	5/14/2009	Pot handle
2174	154	MD	1	6	10	0.5	0	0	5/14/2009	1/2"nose cone
2180	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2181	NA	NMD	3	0	0	0.5	0	0	5/14/2009	Aluminum cans on surface
2182	255	MD	1	8	16	1	0	0	5/13/2009	Nose cone - same as 2081
2183	450	MD	1	10	28	30	180	0	5/15/2009	M38 complete. Same 2055
2184	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2185	125	MD	1	0	0	0.1	0	0	5/13/2009	Initiator receiver
2186	0	NF	0	0	0	0	0	0		NO FIND
2187	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2188	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2189	0	NF	0	0	0	0	0	0	5/12/2009	NO FIND
2190	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2191	750	Non-MD	1	0	0	0.1	0	0	5/19/2009	Wire
2192	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2193	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2196	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2197	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2202	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2203	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2206	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2209	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2212	0	NF	0	0	0	0	0	0	5/14/2009	NO FIND
2215	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2218	0	NF	0	0	0	0	0	0	5/14/2009	NO FIND
2221	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2222	0	NF	0	0	0	0	0	0	5/15/2009	NO FIND
2223	24	MD	1	0	0	0.1	0	0	5/14/2009	Front cap spotting charge
2226	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND
2227	0	NF	0	0	0	0	0	0	5/13/2009	NO FIND

Appendix C: Kirtland Seeded Area
Description of Files

Prove-out site files:

A prove-out site was developed at Double Eagle Airport to assess signal amplitude from representative objects, including two 4.2” mortars, two 155m projectiles, two 105 HEATs, two 105mm projectiles, and two 81mm mortars. These ordnance types are of interest at the Kirtland seeded area. A map plot for one pass over the Double Eagle Prove-out line is provided for reference, in a file named GPO-bin1.tif.

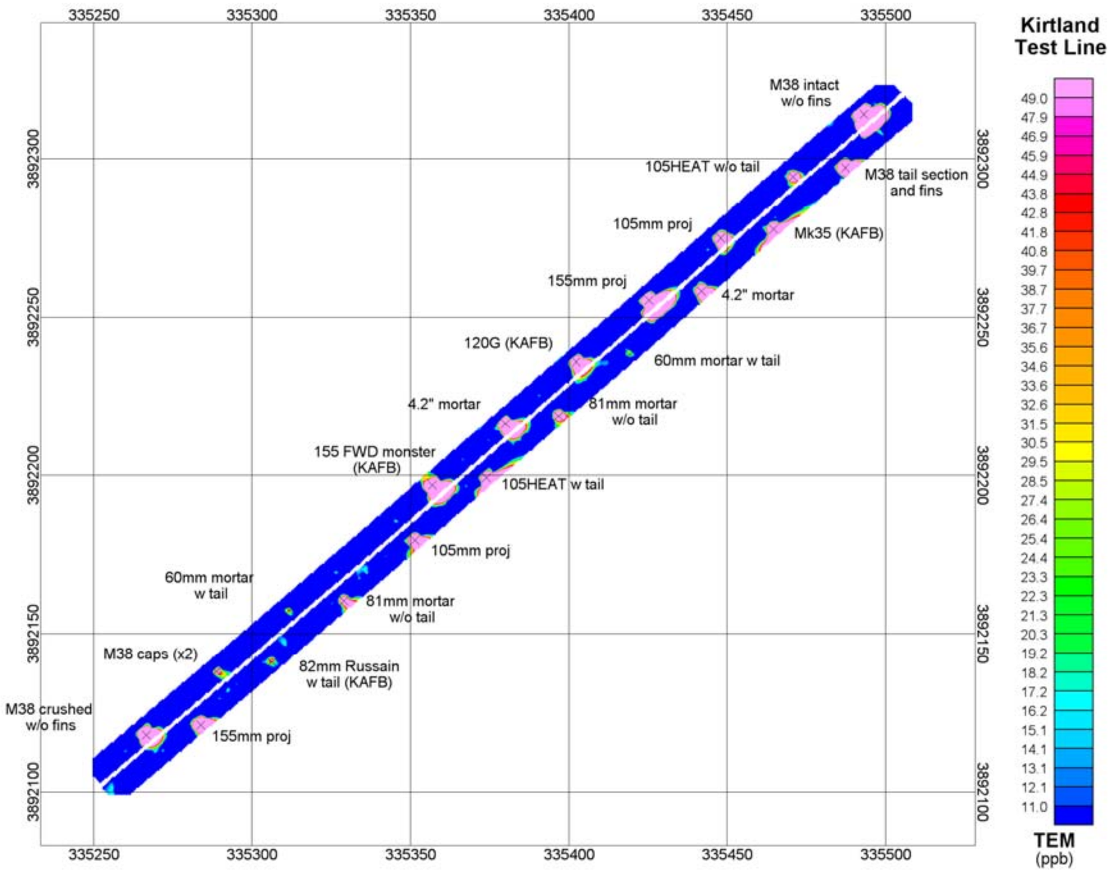


Figure 1: Kirtland calibration line.

Six of the prove-out line items are of interest for the Kirtland seeded area prioritization. We have compiled figures showing the measured signal amplitudes from several passes over the test grid, for each of these items. The figures are attached and named: 81mm_wo_tail_graph_1.jpg, 81mm_wo_tail_graph_2.jpg, 105heat_w_tail_graph.jpg, 105heat_wo_tail_graph.jpg, 105proj_graph_1.jpg, 105proj_graph_2.jpg, 155proj_graph_1.jpg, 155proj_graph_2.jpg, 4.2mortar_graph_1.jpg, and 4.2mortar_graph_2.jpg.

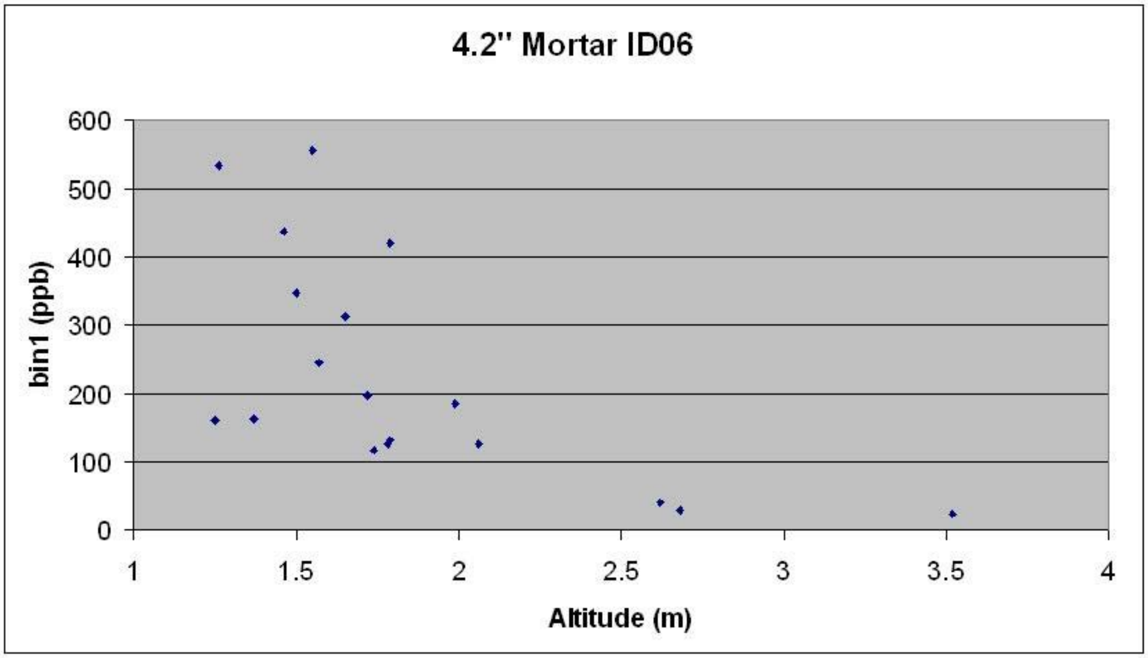


Figure 2: Graph of one of the 4.2” mortars. When the altitude is around 2 m or less the anomaly amplitude is typically greater than 100 ppb.

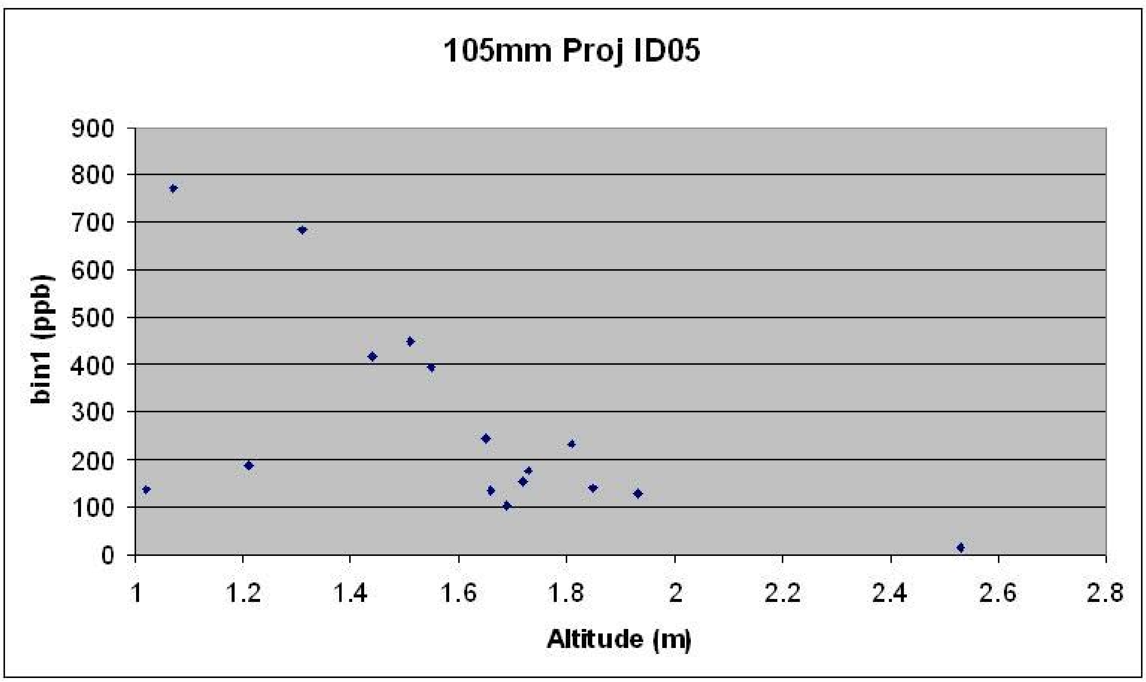


Figure 3: Graph of one of the 105mm projectiles. When the altitude is around 2 m or less the anomaly amplitude is typically greater than 100 ppb.

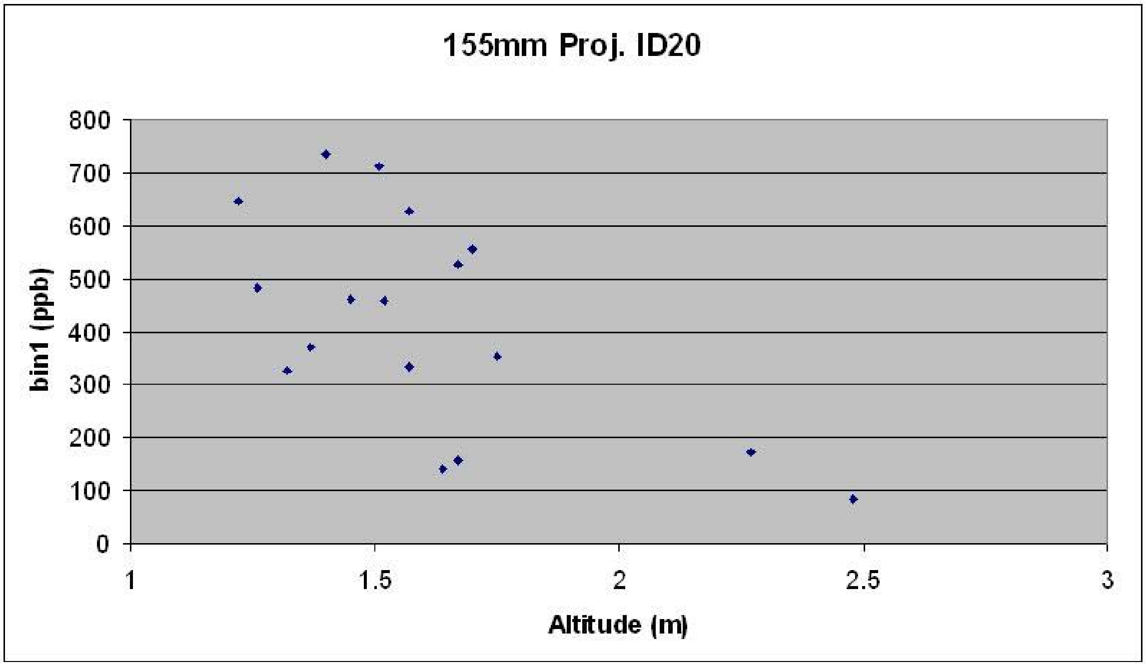


Figure 4: Graph of one of the 155mm projectiles. When the altitude is around 2.3 m or less the anomaly amplitude is typically greater than 100 ppb.

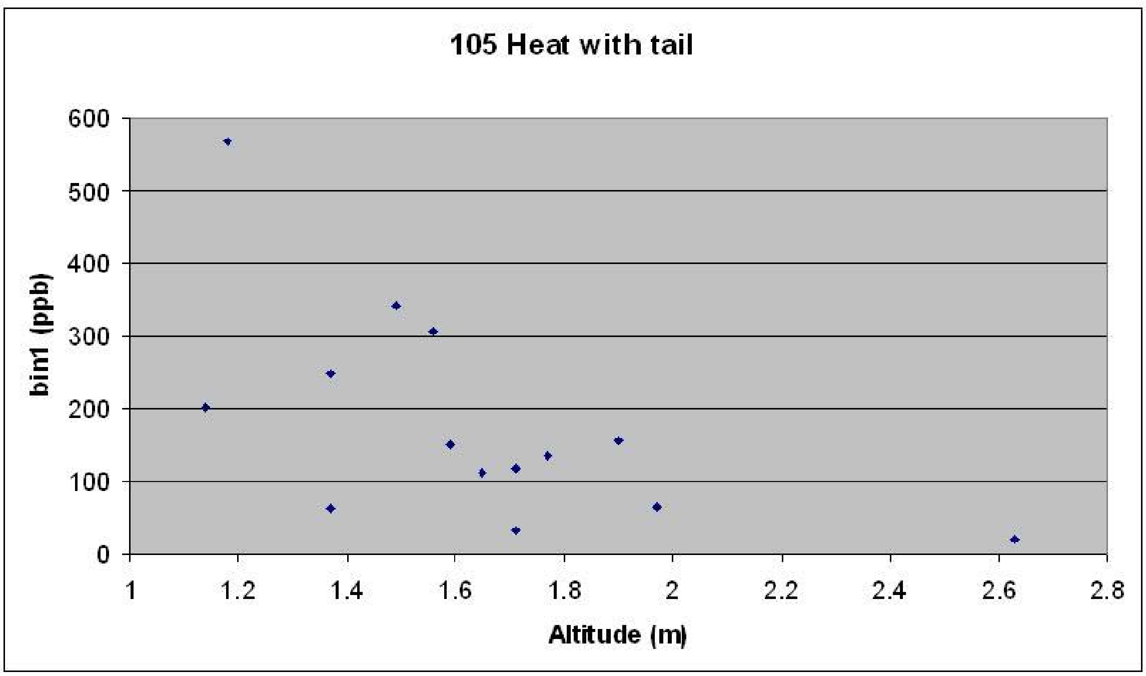


Figure 3: Graph of one of the 105 HEATs. Shows that when the altitude is around 2 m or less the anomaly amplitude is typically greater than 30 ppb and often over 100 ppb.

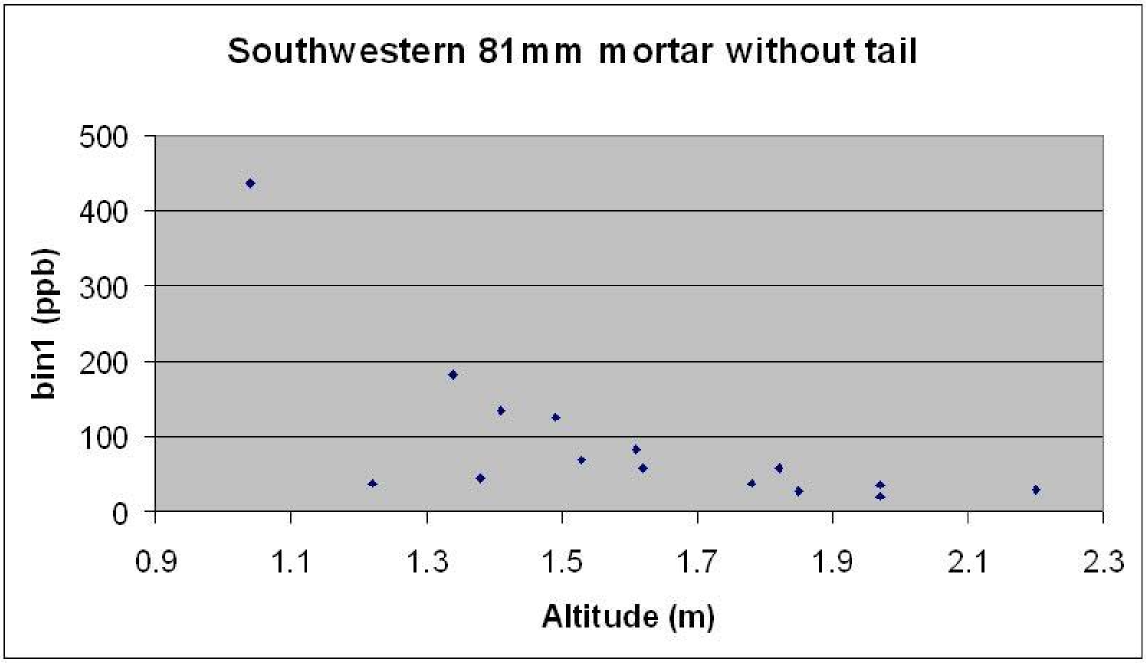


Figure 4: Graph of one of the 81mm mortars. Shows that when the altitude is around 2 m or less the anomaly amplitude is typically greater than 30 ppb and occasionally above 100 ppb; however, in a few cases it may lie between 15 to 30 ppb, near the noise threshold.

Figure 5: Photo of 4.2" mortars.

Figure 6: Photo of 155 projectiles.

Figure 7: Photo of 105 projectiles


Figure 8: Photo of 105 HEATs.


Figure 9: Photo of 81mm mortars.

Note that both bin 1 and bin 2 data were reviewed and the S/N was better for the bin 1 data.

Kirtland Seeded Area

An overview map of the Kirtland area is provided for reference, titled Kirtland_figure.tif and Kirtland_figure_hires.tif.

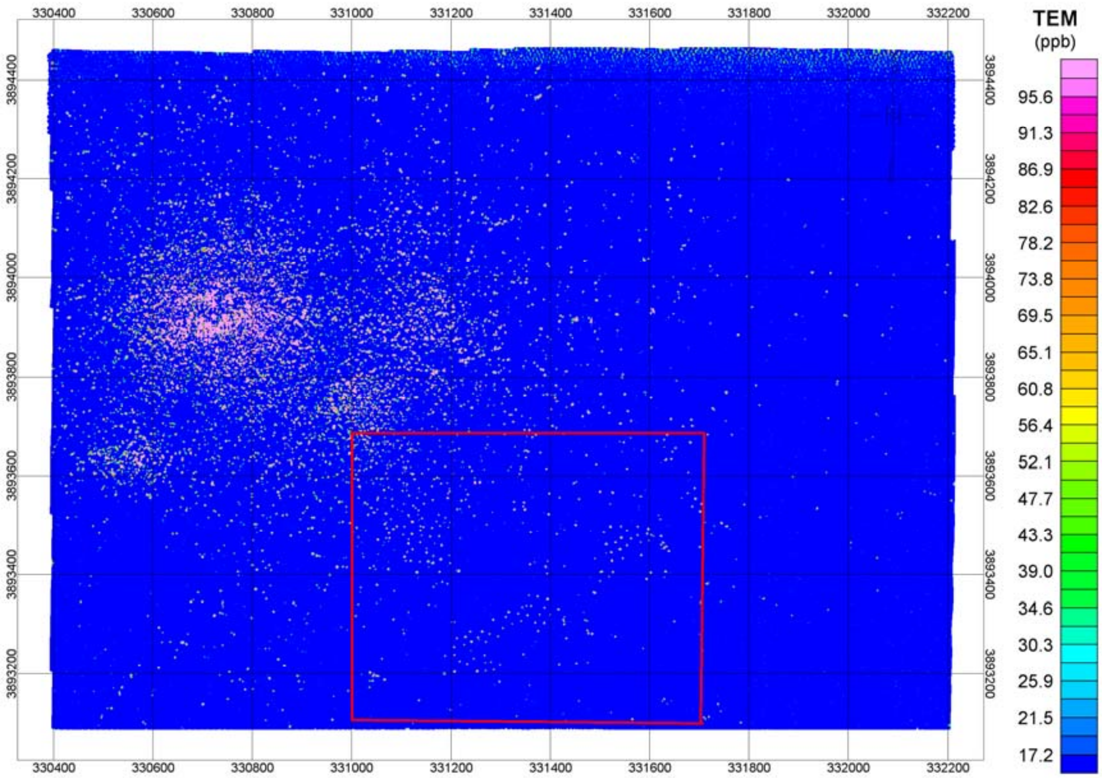


Figure 10: Overview map of Kirtland TEM survey. The seeded area is outlined in red.

An enlarged map of seeeded area is provided in Kirtland_seeded_wtargets.tif (this map includes the targets symbols), and Kirtland_seeded.tif (map without targets symbols).

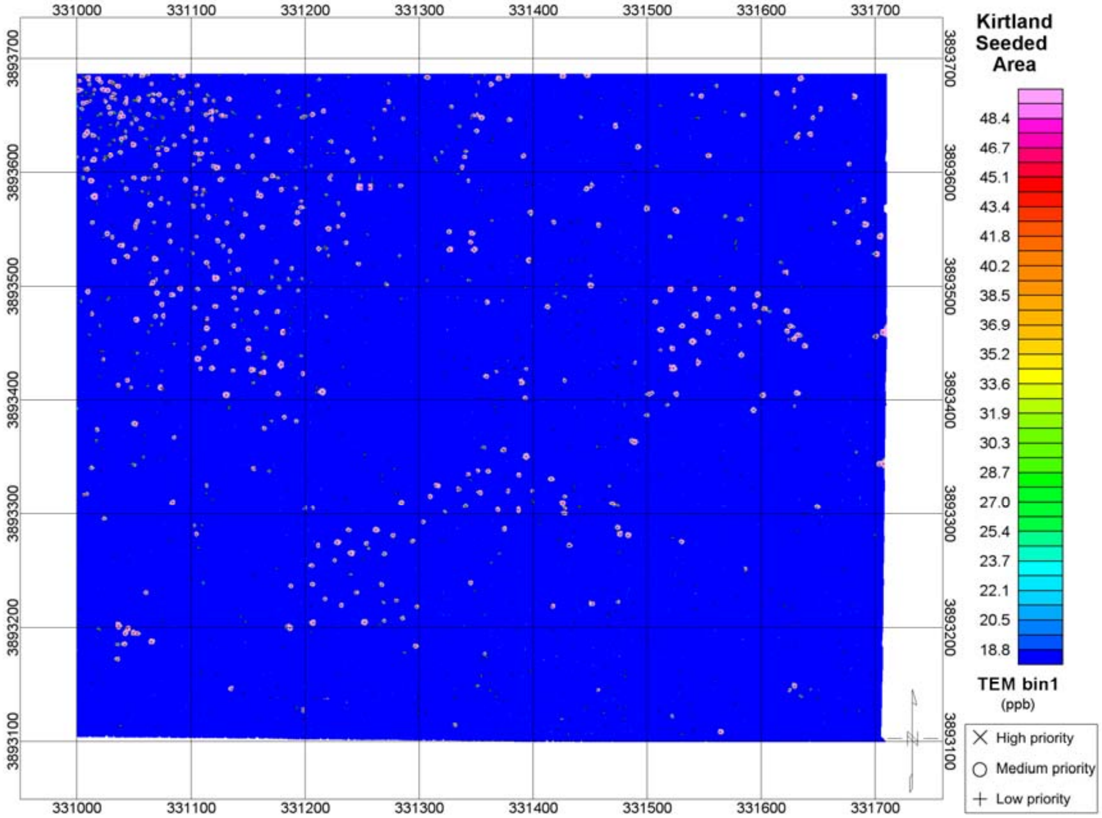


Figure 11: Kirtland seeded area with the target symbols.

The mean altitude (at the receiver coils) for the Kirtland seeded site was 1.3m. An altitude map, Kirtland_seeded_altitude.tif, is included with the other maps.

```
/ ------------------------------------------------------------------
---------
/ Kirtland Seeded Area
/ Coordinate System: WGS84, UTM Zone 13N, meters
/ A_picks greater than 100ppb, B_picks greater than 30ppb and less than
100ppb,
/ C_picks less than 30ppb
/ A_picks = 477, B_picks = 344, C_picks = 471, Total picks = 1292
------------------------------------------------------------------
/
/          UTM_X             UTM_Y        alt      bin1 (ppb)        rank
/============== ================ ========== ===========================
     331690.75       3893554.25        1.2         3301.61           A1
     331393.75       3893350.25        1.0         3020.48           A2
     331215.00       3893407.25        1.2         2795.47           A3
     331522.75       3893428.00        1.3         2493.71           A4
     331396.25       3893522.75        1.1         2415.14           A5
     331179.00       3893430.75        1.4         2372.21           A6
     331397.50       3893564.75        1.0         2351.86           A7
      .
      .
      .
     331237.25       3893684.00        1.3           99.89         B478
     331219.25       3893617.00        1.2           99.52         B479
      .
      .
     331274.00       3893347.00        1.3           29.99         C822
     331481.50       3893468.75        1.2           29.97         C823
     331192.50       3893128.75        1.5           29.96         C824
     331483.75       3893630.50        0.9           29.92         C825
     331559.25       3893221.00        1.1           29.90         C826
     331413.50       3893468.50        1.0           29.90         C827
     331321.00       3893537.00        1.5           29.81         C828
     331262.00       3893631.25        1.5           29.81         C829
```

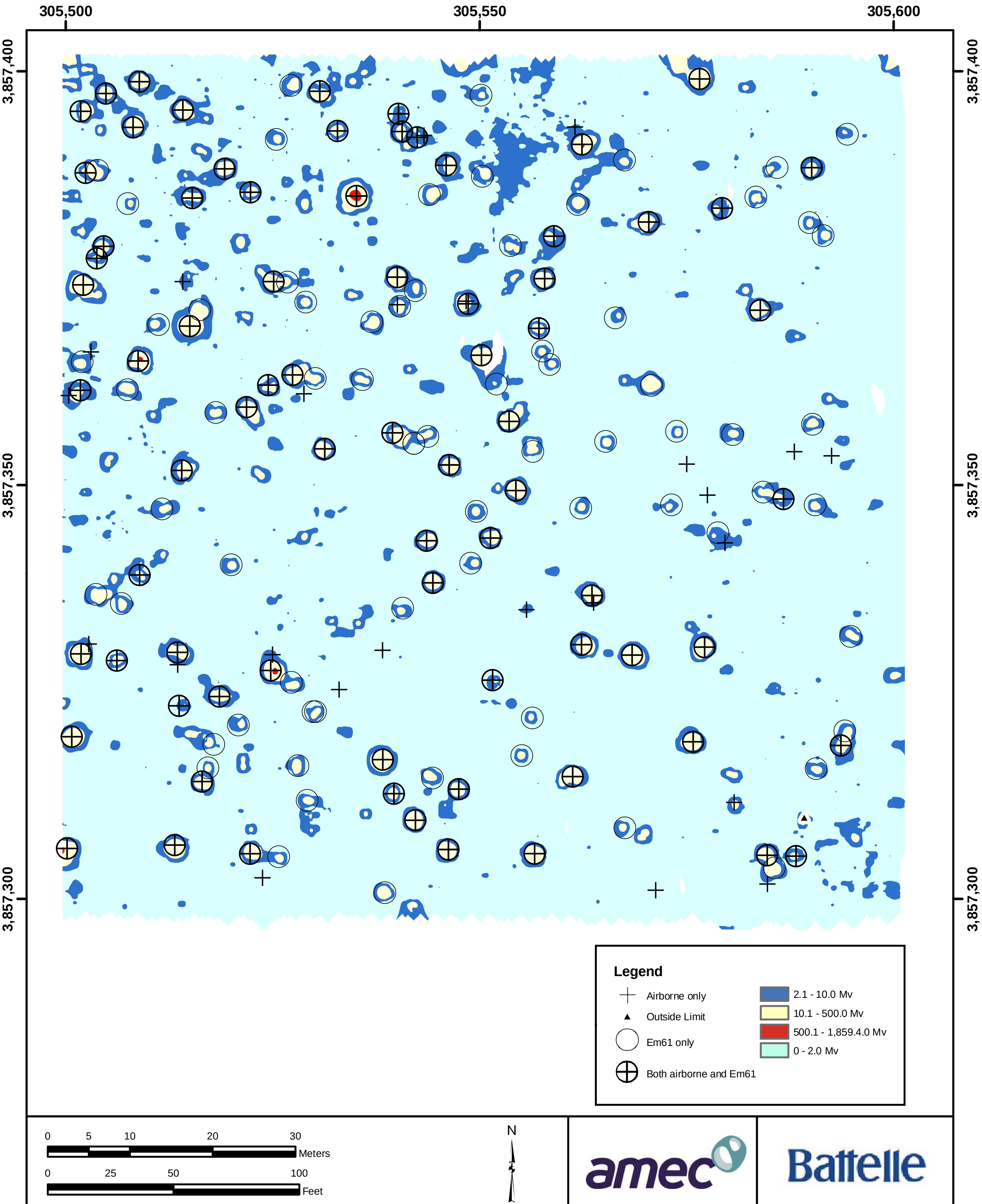
Targets labeled high priority on the map and “A” on the target list are represented by an “X” and are 100 ppb and higher. This threshold should encompass nearly all of the 155mm projectiles, 105mm projectiles and 4.2” mortars, as indicated on the figures presented earlier in this document. Depth of burial is assumed to be less than 0.3m, and if deeper could affect the breakdown of anomalies into the three categories described here.

Targets labeled medium priority on the map and “B” on the target list are represented by circles and are between 30 ppb and 100 ppb, this threshold is taken from the 105 HEAT and 81mm mortar anomalies on the calibration line. This group should include the majority of 81mm mortars, some 105 HEATs, and a few 4.2” mortars.

Targets labeled low priority on the map and “C” on the target list are represented by “+” and are below 30 ppb and above 20 ppb. However, we have done visual inspection and have ranked some higher and some lower on the basis of the profile and map character. This threshold is taken from the 81mm mortar diagram and should include a portion of the 81mm mortars as well as some portion of the larger ordnance items.

Summary table for each figure or file:

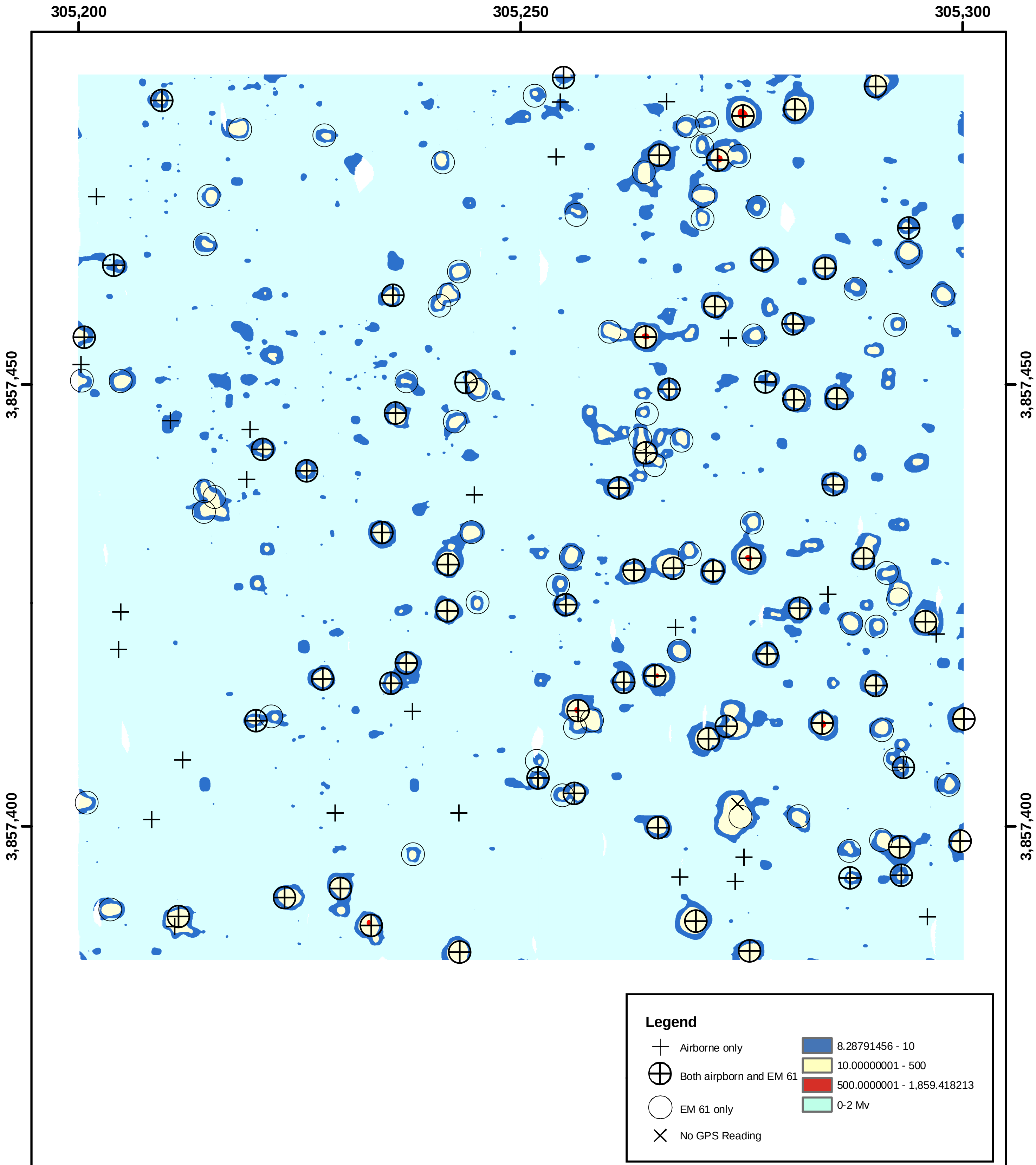
Figure/File	Description
GPO_bin1.tif	map of bin1 for the geophysical prove-out line
Kirtland_figure.tif	map of bin1 for the Kirtland area
Kirtland_figure_hires.tif	high resolution map of bin1 for the Kirtland area
Kirtland_seeded.tif	Map of bin1for the Kirtland seeded area
Kirtland_seeded_wtargets.tif	Map of bin1 for the Kirtland seeded area with targets
Kirtland_seeded_wtarget_hires.tif	Map of bin1 for the Kirtland seeded area with targets at high resolution
Kirtland_seeded_altitude.tif	altitude map of the Kirtland seeded area
4.2mortar_graph_1.JPG	graph of measured signal amplitude vs. altitude for a 4.2” mortar
4.2mortar_graph_2.JPG	graph of measured signal amplitude vs. altitude for a 4.2” mortar
155proj_graph_1.JPG	graph of measured signal amplitude vs. altitude for a 155mm projectile
155proj_graph_2.JPG	graph of measured signal amplitude vs. altitude for a 155mm projectile
105proj_graph_1.JPG	graph of measured signal amplitude vs. altitude for a 105mm projectile
105proj_graph_2.JPG	graph of measured signal amplitude vs. altitude for a 105mm projectile
105heat_w_tail_graph.JPG	graph of measured signal amplitude vs. altitude for a 105 heat with a tail
105heat_wo_tail_graph.JPG	graph of measured signal amplitude vs. altitude for a 105 heat without a tail
81mm_wo_tail_graph_1.JPG	graph of measured signal amplitude vs. altitude for a 81mm mortar without a tail
81mm_wo_tail_graph_2.JPG	graph of measured signal amplitude vs. altitude for a 81mm mortar without a tail
Kirt_seeded_picks.XYZ	prioritized target list of Kirtland seeded area, contains all three prioritizations, “A”, “B”, and “C”
Kirt_seeded_picks_rankA.XYZ	prioritized target list of Kirtland seeded area for ”A” anomalies
Kirt_seeded_picks_rankB.XYZ	prioritized target list of Kirtland seeded area for “B” anomalies
Kirt_seeded_picks_rankC.XYZ	prioritized target list of Kirtland seeded area for “C” anomalies



amec Battelle

PROJECT Intrusive Anomaly Summary Report Kirtland Bombing Range Cibola, New Mexico	SOURCE Grid 4 – EM61 MK2 Color Contour Map of Anomalies and Comparisons S-12 Bombing Target, Pueblo of Laguna, NM	DATE: 09/16/09 PROJECT NO: 3-760-60146
TITLE Grid 1 – EM61 MK2 Map of Anomalies and Comparisons	PROJECTION: WGS 84, UTM 13 North SCALE: 1:610.558688	FIGURE NO: Appendix E

Map Document: (X:\Projects\AFCEE\Kirtland_AFB\MXDs\Figure_7_Grid 1 – EM61 MK2 Color Contour Map of Anomalies and Comparisons.mxd) 8/19/2009 -- 3:10:24 PM



0 5 10 20 30 Meters

0 25 50 100 Feet

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PROJECT Intrusive Anomaly Summary Report Kirtland Bombing Range Cibola, New Mexico	SOURCE Grid 4 – EM61 MK2 Color Contour Map of Anomalies and Comparisons S-12 Bombing Target, Pueblo of Laguna, NM		DATE: 09/16/09 PROJECT NO: 3-760-60146
TITLE Grid 4 – EM61 MK2 Map of Anomalies and Comparisons	PROJECTION: WGS 84, UTM 13 North	SCALE: 1:601.055829	FIGURE NO: Appendix E

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